FY20 FFO Grantee Final Report

I. OVERVIEW

1. Grant Number (Not applicable for federal PIs): NA20OAR0110428

2. Principal Investigator (name, address, contact information):
Amy Gusick
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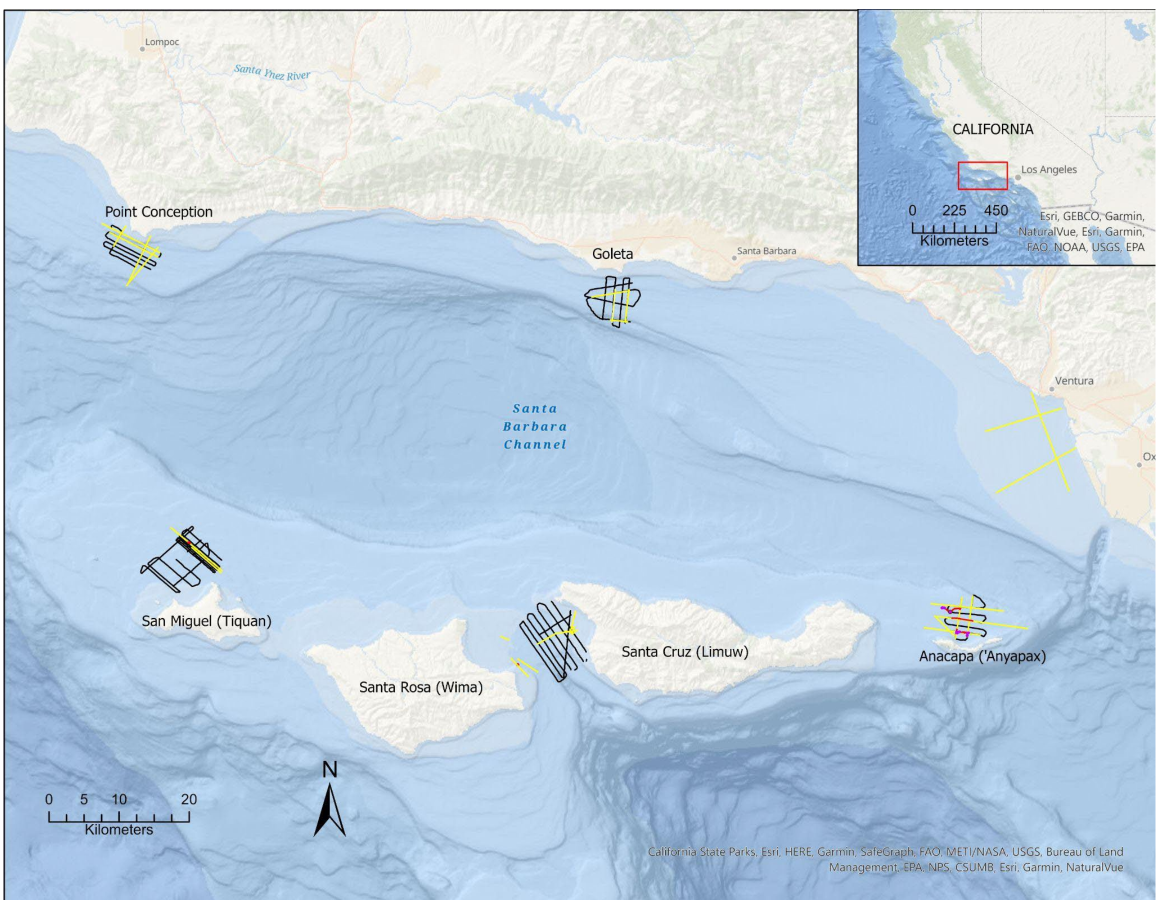
900 Exposition Blvd, Los Angeles, CA 90007-4057 USA

3. Total Award from OER $370,807

4. Project Title: Paleolandscapes, Paleoecology, and Cultural Heritage on the Southern California Continental Shelf

5. Area of Operation: Southern California Bight –Northern Channel Islands and adjacent mainland (see Figure 1 and below)



6. Co-PI(s), Participating Institutions, and personnel:
Jillian Maloney, San Diego State University
Steven Constable, Scripps Institution of Oceanography
Shannon Klotsko, University of North Carolina, Wilmington
Roslynn King, Scripps Institution of Oceanography
Regan Dunn and Emily Lindsey, La Brea Tar Pits
Aaron Celestian, Natural History Museum, Los Angeles
Todd Braje, San Diego State University
Jon Erlandson, University of Oregon
Andrew Mendoza, Santa Ynez Band of Chumash Indians

7. Award Period: From September 01, 2020 To August 31, 2023

II. SUMMARY

II.1. Abstract

This project was a continuation of investigations on the continental shelf of the Southern California Bight (SCB). We sought to expand knowledge on the paleolandscape and paleoenvironment of the region off the northern Channel Islands and adjacent mainland through collection of geophysical data focused on identification of hydrocarbons and samples of identified tar seeps. To accomplish these goals, we first collated data from previous research on which the project collaborators had worked, as well as publicly available hydrocarbon data and reports from the region. From these data we created paleolandscape maps that targeted sections of the continental shelf that were subaerial during the Early Holocene and terminal Pleistocene and possibly harbored tar seeps. Next we conducted two survey cruises collecting subbottom profiler and controlled source electromagnetic (CSEM) data and co-located those areas that showed hydrocarbon activity in the CSEM and associated unique features in the subbottom data. In all we collected 125 linear kilometers (km) of CSEM and over 260 linear km of Chirp subbottom data. From these data we selected 25 targets for remote operated vehicle (ROV) investigation. We conducted one ROV survey and sample collection cruise in January 2023, after a last minute cancellation by the ship operator for a March 2022 ROV survey cruise. Weather forced investigation of only four of our planned ROV targets, all to the north of Anacapa Island. While no tar seeps were identified in this region, we did identify a shallow water cold seep, the first known in southern California. This seep has been given the S^{h}amala (Chumashan language) name *Ma saputiwaxmu'* (the place where it seeps through) by the Cultural Department at the Santa Ynez Band of Chumash Indians. This tribe is one band of the Chumash people, the original caretakers of the land where this research was conducted. We collected 14 rock samples and 4 sediment samples during 13 ROV dives and over 33 hours of bottom time investigating this seep field. Although we were unable to collect data from tar seeps that may have provided data on ancient plant and animal specimens, we have discovered several areas on the continental shelf that show hydrocarbon signatures and warrant further investigation. We have also collected geophysical data from previously unmapped portions of the continental shelf that has added to our understanding of paleolandscape formation in the region and we have identified sensitive habitats that need additional study. Lastly, we have shown that inclusion of CSEM data on geophysical survey for landscape characterization is beneficial to identifying not only hydrocarbon features, but also other features such as shell deposits. These types of data are critical to support on-going efforts to identify and protect cultural landscapes, features, and material on the continental shelf of Southern California.

II.2. Purpose of Project

II.2.a. Describe topic and/or questions that were addressed

Sea-level rise following the Last Glacial Maximum (LGM) (~20 kya) submerged millions of square kilometers (km^2) of coastal landscapes around the world, complicating efforts to understand the paleolandscapes, paleoecology, human dispersals, and the cultural history of these now drowned regions. This situation is particularly troublesome in the Southern California Bight on the eastern Pacific Coast where sea-level rise inundated thousands of km^2 of coastal terrain, including entire islands (Clark et al. 2014). Still, this region boasts one of the highest densities of terminal Pleistocene (15,000-11,500 calibrated years before present [cal BP]) and early Holocene (11,500-8,000 cal BP) archaeological sites in the New World (Gusick and Erlandson 2019). Many of these island and mainland sites have produced midden deposits with abundant shellfish remains, fish, bird, or sea mammal bones, and/or technologies commonly associated with the harvest of maritime resources. This suggests: 1) that the earliest occupants of the SCB were seafaring maritime hunter-gatherers; and 2) that additional Paleocoastal archaeological sites (~15,000-8,000 cal BP) are likely located on the submerged landscapes of the Pacific Coast.

In the SCB region, researchers have successfully identified hundreds of subaerial Paleocoastal archaeological sites by focusing on landscape features and habitats known to attract early peoples (e.g., Braje and Erlandson 2008; Erlandson 1994; Erlandson et al. 2011; Gusick 2013; Rick and Erlandson 2012; Rick et al. 2013). The search for these sites has extended onto the regional continental shelf, but Paleocoastal sites have not yet been identified on this submerged landscape. Previous research by the project Principal Investigators (PIs) suggested that with the right technologies, however, features such as paleochannels, paleoestuaries, and offshore tar seeps (see Appendix E for definitions) – all features used by indigenous communities during the terminal Pleistocene and Holocene along the Pacific Coast – can be identified and used to model archaeologically and biologically sensitive submerged landscapes (Braje et al. 2016, 2019; Gusick et al. 2019; King et al. 2018; Laws et al. 2019; Maloney et al. 2017, 2018; Tahiry et al. 2018). By focusing on features that were attractive to early maritime hunter-gatherers – fresh water, estuaries, toolstone outcrops, and tar seeps – we can not only provide data germane to geological, biological, and paleontological disciplines, but also narrow search parameters to identify archaeological “hot spots" on the continental shelf. These data are crucial in our ability to identify sensitive cultural landscapes and eventually identify, document, and preserve underwater cultural heritage resources.

Methods for identifying submerged pre-contact archaeological sites, or the “hot spots” that may contain them, have advanced over the past few decades. It is common to collect data from seismic profiling systems, side scan sonar, and bathymetry from multibeam echosounders to reconstruct landscape features and paleodrainages and target anomalies for testing via coring, grab samples, or diver/ROV investigation (*inter alia* Adovasio and Hemmings 2009; Blanton and Margolin 1994; Evans 2014; Faught 2002, 2004; Fillon 2006; Garrison 2006; Gusick and Faught 2011; Gusick et al. 2019; Halligan et al. 2016; Merwin 2006). While some can be universally applicable, regionally specific methods are necessary for efficacy across environmental variables. For instance, geological and environmental features that should be targeted as important indicators of archaeological sites, and therefore included in models and search parameters, will vary and depend on local cultural histories and preservation potential, among other factors (Gusick and Faught 2011). In the SCB region, focusing on paleochannels, paleoestuaries, and tar seeps provides an opportunity to explore new methods and technologies used for maritime archaeological research. This strategy also provides opportunities to collect novel and broad scale data on paleoecology, paleogeography, and cultural heritage.

Our research included both traditional and emerging methods for offshore landscape characterization and buried target identification. We conducted a combination of Chirp subbottom profiler and CSEM survey for paleolandscape reconstruction and to identify areas that contain hydrocarbon, specifically tar seeps. To groundtruth the Chirp and CSEM geophysical signals, we then conducted a ROV survey with video to visualize the submerged landscape and collect geological samples. Using these methods that build upon each other provides numerous lines of data that can address our main research questions on the character of the terminal Pleistocene and earliest Holocene landscapes. It is on these now submerged landscapes that some of the earliest maritime inhabitants living on the eastern Pacific shoreline adapted to the major climate changes that occurred at the end of the LGM. By reconstructing paleolandscape formation and identifying paleoecological shifts during these early human occupation periods, we are able to target sensitive cultural and biological areas across this now submerged landscape.

II.2.b. Describe/list the project objectives

1) Identify three specific features: paleoestuary deposits, paleochannels, and tar seeps – Previous broad scale remote sensing surveys have provided data to target areas for feature identification. Paleoestuary deposits can provide data on paleoenvironmental conditions and habitat changes over time. The evolution of paleochannels provide data on landscape and environmental changes. Tar seeps can provide data on paleoecology as well as sources of a mineral critical to maritime peoples. Maritime hunter-gatherer groups in the region used these features, and they can be used to delineate sensitive archaeological areas, and narrow the search for cultural deposits.

2) Identify cultural shell midden deposits – Paleocoastal sites in the region include numerous shell midden deposits that contain artifacts and ecofacts. We expect to find similar sites, dating to these time periods, in the submerged environment, especially in areas of lower wave energy where they were protected from marine erosion (Erlandson 2016).

3) Collect flora, fauna, and sediment samples – To reconstruct paleoecology and the paleolandscape, flora, fauna, and sediment samples can provide material for radiocarbon dating, magnetic susceptibility testing, eDNA analysis, quantitative mineralogy, and ancient plant and animal identification.

4) Refine map of submerged paleolandscape – Collection of the Chirp data as well as the new CSEM data will contribute to the ongoing mapping of paleolandscapes and provide further understanding of the Pleistocene maritime landscape of the SCB.

II.3. Approach

II.3.a. Describe the work that was performed

Operations for this research occurred in the water of the U.S. Southern California Coast over a two year time period and included collection of Chirp subbottom and CSEM geophysical data and a ROV survey with sample collection (Figure 1). Two initial cruises focused on geophysical data collection and were informed by previously collected subbottom, side scan, and core data gathered as part of a BOEM cooperative agreement (M15AC00012) on which Maloney, Gusick, Braje, and Erlandson were co-PIs and Klotsko and King were collaborators. These previous data were considered when choosing target locations for the current study. The subbottom and CSEM data collected during the current study were processed and analyzed in conjunction with previous data to inform the dive plan for the ROV survey.

Geophysical surveys (Chirp & CSEM)

From September 25 to October 5, 2021 and March 7 to March 11, 2022**,** CSEM and sonar mapping operations were conducted aboard the R/V *Bob & Betty Beyster,* Cruise ID BBB21-09 (Table 1) and the R/V *Shearwater*, Cruise ID SHW22-03 (Table 2). These cruises collected a combination of baseline and more detailed data and information using a Chirp subbottom profiler (Edgetech 512) and surface-towed (Porpoise) and deep-towed (Compact Undersea Electromagnetic Source Instrument [CUESI]) CSEM north of San Miguel Island (SMI), in-between Santa Rosa and Santa Cruz islands (Santa Cruz Passage [SCP]), north of Anacapa Island (ANA), and offshore from the California mainland adjacent to the Santa Clara River (VEN), Point Conception (PtC), and Goleta/Coal Oil Point (COP).We collected 25 GB of CSEM data over 124.12 km of linear survey and 7 GB of Chirp data over 260 km of linear survey (see Table 12).

Table 1. On ship and ground crew for R/V *Beyster* cruise

Aboard Vessel		
Name	**Affiliation**	**Title/Role(s)**
Amy Gusick	NHM	Chief Scientist, Archaeologist, MWF*
Jillian Maloney	SDSU	PI, Marine Geologist, MWF
Roslynn King	SDSU/SIO	Graduate Student, Geophysicist, CSEM Technician
Chris Amerding	SIO	Collaborator, Geophysicist, CSEM Technician
Steven Constable	SIO	Collaborator, Geophysicist, Director CSEM Lab
Andrew Mendoza	SYBCI	Chumash Intern
Eva Pagaling	CINMS	Chumash Volunteer
David Ball	BOEM	Regional Historic Preservation Officer, MWF
Chloe Gufstafson	SDSU/SIO	Post-Doc, Geophysicist, CSEM Technician
Jessica Portner	NHM	Journalist
Edgar Chamorro	NHM	Videographer
David Ono	ABC7	Filmmaker/News Anchor
Andres Pruna	Univision	Videographer/Producer
Ground Support		
Name	**Affiliation**	**Title/Role(s)**
Jimmy Johnson	SYBCI	Chumash Intern
Jake Perez	SIO	Collaborator, Geophysicist, CSEM Technician
Shannon Klotsko	UNCW	Collaborator, Marine Geologist, Subbottom/Multibeam Technician
Todd Braje	SDSU	Collaborator, Archaeologist
Jon Erlandson	UO	Collaborator, Archaeologist
Emily Lindsey	LBTP	Collaborator, Paleontologist
Regan Dunn	LBTP	Collaborator, Paleobotanist

*MWF = Marine Wildlife Monitor

Table 2. On ship and ground crew for R/V *Shearwater* cruise

Aboard Vessel		
Name	**Affiliation**	**Title/Role(s)**
Amy Gusick	NHM	Chief Scientist, Archaeologist, MWF
Shannon Klotsko	UNCW	Co-PI, Marine Geologist, MWF
Zac Montgomery	CINMS	Vessel Crew
Matt Howard	CINMS	Vessel Crew
Jackie Buhl	CINMS	Vessel Crew
Ground Support		
Name	**Affiliation**	**Title/Role(s)**
Jillian Maloney	SDSU	Co-PI, Marine Geologist

ROV Target Identification

In some survey locations, the new Chirp data did not reveal many features below the seafloor, which made it difficult to identify paleochannel and paleoestuary features. However, there were several different signals observed in the water column above the seafloor (water column signals). Emission of gas from the seafloor, which is associated with the presence of hydrocarbons including tar, can be imaged in the water column above seeps. We identified five different water column signal types that may indicate the presence of hydrocarbons in the Chirp data and mapped their extent across the study areas (see section II.4.a.iv). In the CSEM data, resistive features potentially indicative of hydrocarbons were also mapped and categorized as high, medium, and low priority (see section II.4.a.ii).

Using the mapped Chirp signals, mapped CSEM resistors, and available bathymetry data, locations for ROV surveys and sampling were selected (Table 4). Locations that showed a co-occurrence of a CSEM resistor indicative of hydrocarbon and one of the five different water column signatures were the primary targets. We attempted to target each of the five different Chirp water column signals and a variety of CSEM resistor types. Bathymetry data were also helpful in matching geophysical signals with seafloor morphology that can reflect seeps (e.g., pockmarks, tar mounds). Although ROV targets were identified prior to the ROV survey, decisions on where to explore and then where to collect samples with the ROV were ultimately made on the ship based on sea state, ship schedule and safety, ROV capability, and ROV survey observations. We originally identified five targets offshore Coal Oil Point, eight offshore Point Conception, five offshore San Miguel Island, and six offshore Anacapa Island. We were able to visit one site offshore Coal Oil Point for a brief ROV survey with minimal visibility. We were not able to reach any ROV survey targets at Point Conception or San Miguel Island. We visited all ROV targets north of Anacapa Island and visited an additional target area with a large seafloor pockmark. From the Anacapa ROV dives, we collected a total of 14 rock samples and 4 sediment samples, which were kept frozen and analyzed in the Mineralogy Laboratory at the Natural History Museum Los Angeles County (NHMLA).

ROV Survey and Sample Collection

From January 2 to January 12, 2023 ROV survey and sample collection occurred aboard the R/V *Sally Ride*, Cruise ID SR2301 (Table 3). This cruise was rescheduled from mid-2022 due to a covid-related staffing complication at Scripps. We used Marine Applied Research & Exploration (MARE) ROV *Beagle*. The *Beagle* is used for image, sample, and data collection in the ocean environment at depths of 15 m to 1,000 m. The ROV system is fully integrated with an array of video cameras, lights, scaling lasers, a digital still camera, 5 function manipulator, multi-beam sonar, USBL positioning tracking system, CTD+DO2, altimeters, and recording equipment.

During this January 2023 cruise, the southern California region was hit with a powerful atmospheric river that severely limited our ability to conduct ROV operations. Most of our target areas were inoperable due to dangerous waters. Those areas that were navigable experienced strong turbidity, rendering visibility of the ROV cameras at virtually null. The area north of Anacapa Island was the only one of six locations that had decent visibility and was considered safe to operate by the R/V *Sally Ride* captain. Therefore, the majority of the ROV survey and all sample collection occurred in the area north of Anacapa Island. We were able to ground truth signals from the CSEM and subbottom that were collected on previous cruises and we identified numerous areas exhibiting hydrocarbon signals, including identification of a shallow water (<100m) cold seep, the first in southern California. We completed a total of 13 dives, gathering 14 rock samples and 4 sediment samples while capturing 33.5 hours of video footage via high-resolution forward and downward-facing cameras.

Table 3. On ship crew for R/V *Sally Ride* cruise

Aboard Vessel		
Name	**Affiliation**	**Title/Role(s)**
Amy Gusick	NHM	Chief Scientist, Archaeologist
Jillian Maloney	SDSU	Co-PI, Marine Geologist
Roslynn King	Scripps	Post-Doctoral Chief Scientist
Dirk Rosen	MARE	ROV crew
Kyle Palmer	MARE	ROV crew
Jordan Stovall	MARE	ROV crew
Andy Lauermann	MARE	ROV crew
Andrew Martinez	SYBCI	Tribal Knowledge Holder

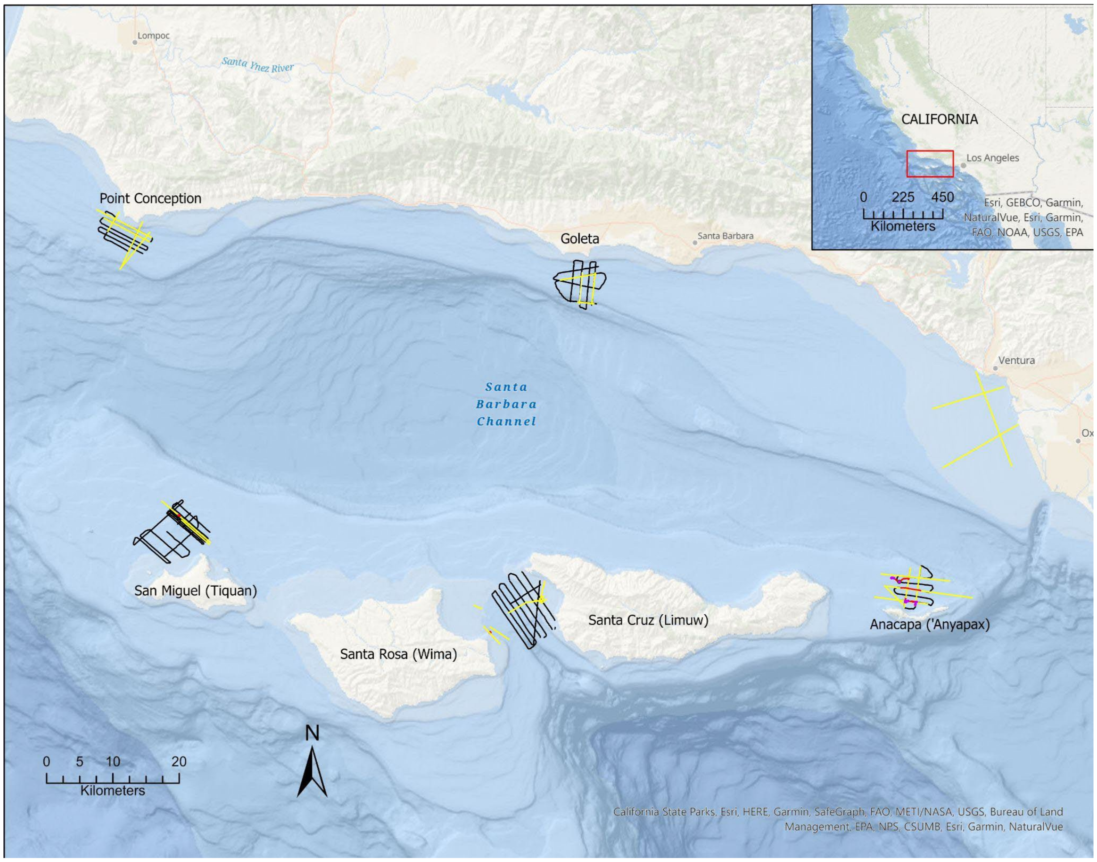


Figure 1. Regional view of locales where subbottom, CSEM, ROV and sample data were collected. Black lines represent subbottom transects, yellow lines represent CSEM transects, red lines indicate ROV survey paths, and purple dots show where samples were collected.

Table 4. Planned ROV dive sites based on Chirp, CSEM, and bathymetry signals.

Name	Location	Chirp Signal	CSEM Signal	Bathymetry Signal	ROV Dives	ROV Samples
ROV01	COP	waterfall haystack	COP_L3, COP_AL3E	no data	No	NA
ROV02	COP	large haystack	no CSEM data	pockmarks	No	NA
ROV03	COP	haystack adjacent to waterfall	COP_AL2W	no data	Dive 4	None
ROV04	COP	waterfall	COP_L4	no data	No	NA
ROV05	COP	blotchy haystack	no resistor mapped	no data	No	NA
ROV06	PtC	strong haystack	PtC_L3N	large mound	No	NA
ROV07	PtC	waterfall	PtC_L1E	large mound	No	NA

Name	Location	Chirp Signal	CSEM Signal	Bathymetry Signal	ROV Dives	ROV Samples
ROV08	PtC	series of haystacks	discrete resistor	small mounds	No	NA
ROV09	PtC	none	discrete resistor	large mound	No	NA
ROV10	PtC	none	discrete resistor	large mound	No	NA
ROV11	PtC	no Chirp data	PtC_L5N	large mound	No	NA
ROV12	PtC	discrete haystack stringy	no CSEM data	blocky seafloor	No	NA
ROV13	PtC	discrete haystack stringy	no CSEM data	blocky seafloor	No	NA
ROV14	SMI	none	SMI_L2N	blocky/rocky seafloor	No	NA
ROV15	SMI	discrete stringy blotchy	No CSEM data	small mound	No	NA
ROV16	SMI	none	SMI_L1N	blocky/rocky seafloor	No	NA
ROV17	SMI	stringy/blotchy	SMI_L2C	blocky/rocky seafloor	No	NA
ROV18	SMI	stringy	SMI_L2S	rocky seafloor	No	NA
ROV19	ANA	none	ANA_L1E, ANA_L1S	rocky dipping beds	Dive 7; Dive 11	Rk4; Rk5; Rk13
ROV20	ANA	stringy	ANA_L1W	rocky dipping beds	Dive 1; Dive 10; Dive 11	Rk1; Rk9; Rk10; Rk11; Rk12
ROV21	ANA	discrete	ANA_L2S	rocky dipping beds	Dive 1	None
ROV22	ANA	discrete/blotchy	ANA_L4C	smooth within large bedforms	Dive 2	None
ROV23	ANA	haystack	ANA_L2N	smooth within large bedforms	Dive 12/13	None

Name	Location	Chirp Signal	CSEM Signal	Bathymetry Signal	ROV Dives	ROV Samples
ROV24	ANA	discrete/blotchy haystack/stringy	No CSEM data	pockmarks	Dive 9; Dive 12/13	Sd1; Sd2; Sd3; Sd4; Rk14
ROV512	SMI	None	None	smooth channel between rocky outcrops	Dive 6	NA - Chirp recovery location, no additional time for seep survey
ROV_A1*	ANA	No Chirp Data	No CSEM data	large pockmark	Dive 3; Dive 8	Rk2; Rk3; Rk6; Rk7; Rk8
ROV_SCP1*	SCP	None	Resistor?	bedforms	Dive 5	None
*Unplanned ROV dives prior to SR2301 cruise						
COP - Coal Oil Point; PtC - Point Conception; SMI - San Miguel Island; ANA - Anacapa Island; SCP - Santa Cruz Passage						

Sample Analyses

Two of the samples (RK-1 & RK-8) collected aboard the R/V *Sally Ride* were analyzed in the Mineralogy Laboratory at NHMLA by Dr. Aaron Celestian. These samples were collected in and around the hydrocarbon signals identified with the CSEM and surveyed with the ROV Beagle. These two samples were selected as one appeared to be a carbonate and the other a non-carbonate and appeared to be representative of the other carbonate and rock non-carbonate samples collected. Chemical composition of the samples was analyzed using X-ray fluorescence (XRF) spectrometry and mineralogy was determined with powdered X-Ray Diffraction (XRD). These analyses were initial and designed to provide a general understanding of the materials collected and will inform further analyses. Oxygen amounts were calculated based on weight percentage oxide for the elements.

Tribal coordination, outreach, and participation

Formal tribal consultation was conducted by NOAA, and Gusick assisted with the tribal outreach. As the area in which this work was conducted is the traditional territory of the Chumash people, Consultation was undertaken with the Santa Ynez Band of Chumash Indians, the federally-recognized tribe of the Chumash. Tribal outreach was also conducted with all bands of the Chumash as well as the Channel Islands National Marine Sanctuary Chumash Community Working Group. In addition, we offered two paid internships on the project that supported Chumash community members. As a result of this outreach, we partnered with two members from the Chumash community who joined us on our geophysical cruise on the R/V *Beyster* and on our ROV and sample cruise aboard the R/V *Sally Ride*. These partnerships were integral in our understanding of cultural landscapes and indigenous ways of knowing within and around the area where the research was focused. The Chumash community members wanted to better understand the technical aspects of how to do the underwater work, and were generous in their sharing of indigenous knowledge about the landscape, cultural histories, sacred spaces, and traditional practices. This type of information is specialized and critical to a more holistic conceptualization of the deep time knowledge we strive to understand with our research. This indigenous knowledge is a contributing factor to our data with which we consider paleolandscape and paleoecology and how humans interacted with and conceptualized their cultural spaces throughout their long occupation on these landscapes. Examples of the outreach documents are provided in Appendix A.

An additional aspect of outreach for this research included working with an artist aboard the R/V *Sally Ride*. Alejandro Cano-Lasso is an artist and early-career scientist focused on a multidisciplinary approach to marine conservation. He creates art to communicate scientific research and to inspire the general public to care for science and the ocean. This is accomplished in various media and by both hand-drawing and digital software to produce natural history plates, scientific figures, and art installations. Alejandro created a project titled Ocean Lines, which was inspired by the research and the physical act of collecting the subbottom data. Future plans to work with Alejandro through NHMLA to communicate the marine science that we conduct in a unique and artistic way for a broad audience. A report with exhibit design and artwork inspired by this research can be found in Appendix B.

II.3.b. Describe how the project was organized and managed

The project was organized with a core team of Co-PIs and significant participants collating information and handling logistics, with a larger team of collaborators kept informed of the project progress and tasked with information gathering and assistance based on their expertise. The main tasks of the project included: 1) project outreach; 2) initial data analysis and general survey location selection; 3) geophysical survey including subbottom and CSEM and data processing; 4) analysis of geophysical data and selection of targets for ROV survey and possible sample collection; 5) sample collection decisions during survey; 6) sample processing and analysis; 7) data synthesis and final report preparation. Below is a list of the individuals who managed various aspects of these tasks.

Amy E. Gusick - Co-Principal Investigator

Dr. Amy Gusick is Curator of Anthropology and Native American Graves Protection and Repatriation Act Office at NHMLAC. Dr. Gusick and Co-PI Maloney directed the project and managed all aspects of project development, logistics, data gathering, analysis, and report writing. Dr. Gusick also took the lead on working with Tribal partners and developed project outreach materials.

Jillian Maloney - Co-Principal Investigator

Dr. Jillian Maloney is an Associate Professor of Geological Sciences at San Diego State University (SDSU) with extensive experience in high-resolution sonar data collection, processing, and interpretation. Dr. Maloney and Co-PI Gusick directed the project and managed all aspects of project development, logistics, data gathering, analysis, and report writing. Dr. Maloney took the lead on data collation and interpretation.

Roslynn King - Significant Participant

Dr. Roslynn King is a Postdoctoral Fellow at University of California, San Diego with extensive experience in CSEM data collection, processing, and interpretation. Dr. King took the lead on all CSEM data collection, processing and analysis. She assisted with ship planning logistics and supplemented this research with a student award of eight days of ships funds through the University of California (UC) Ship Funds program on the R/V *Sally Ride* for the ROV data and sample collection cruise of which she was the Chief Scientist. She assisted in all data analysis and report writing.

Steven Constable - Significant Participant
Dr. Steven Constable is Professor of Geophysics at the Scripps Institution of Oceanography (SIO), and director of the Marine Electromagnetic (EM) Lab at SIO. Dr. Constable assisted with operation of the EM instruments and data analysis.

Shannon Klotsko - Significant Participant
Dr. Shannon Klotsko is an Assistant Professor of Geology at the University of North Carolina, Wilmington (UNCW). Dr. Klotsko collaborated on research cruise planning and directed subbottom data collection and processing. She assisted with data interpretation and identification of ROV targets, and contributed to report preparation.

Regan Dunn - Collaborator
Dr. Regan Dunn is an Associate Curator at the La Brea Tar Pits. She collaborated on target identification and sample collection planning for possible tar seeps. Dr. Dunn also consulted on sample collection during the ROV survey.

Aaron Celestian - Collaborator
Dr. Aaron Celstian is Curator for Minerals at NHMLAC. He collaborated on sample identification and performed all analyses on the samples collected during the ROV survey. He also contributed to final report preparation.

Todd Braje - Collaborator
Dr. Todd Braje is Executive Director of the Museum of Natural and Cultural History at the University of Oregon. He contributed to overall project conceptual design and theoretical direction.

Jon Erlandson - Collaborator
Dr. Jon Erlandson is Professor Emeritus in the Anthropology Department and former Executive Director of the Museum of Natural and Cultural History at the University of Oregon. He contributed to overall project conceptual design and theoretical direction.

II.3.c. Describe how data were organized, processed, and archived to meet NOAA data management requirements

We organized, processed, and archived our project data in compliance with National Oceanic and Atmospheric Administration (NOAA) and Federal government data policy and regulations discussed in Section VIII.B of the original project announcement and in our Data Management plan. Project data are organized by type of analysis and are curated with available metadata. Metadata records describe instrument type and analysis parameters, date/time of data collection, the scientist that oversaw the data collection, why the data were collected, where the data are housed, and any processing or post-processing that any data have received. Spatial metadata is curated in ISO 19139 format.

Subbottom

Chirp subbottom data were collected on the R/V *Shearwater* and the R/V *Sally Ride.*

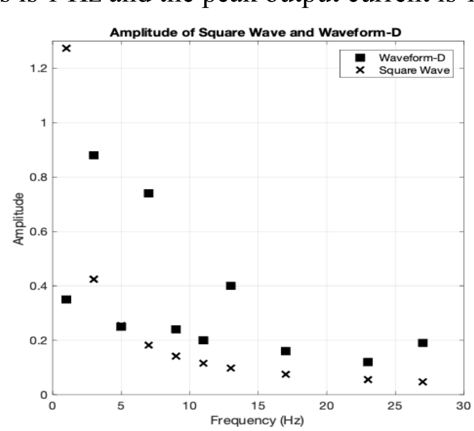
R/V *Shearwater*

UNCW's EdgeTech 512i towfish was used to collect seven GB of Chirp subbottom data over 250 km of linear survey on this cruise. Chirp subbottom data were recorded in SEG-Y format, along with real-time GPS data for position accuracy. These data were processed using SIOSEIS (Henkart 2006) and Seismic Unix (Cohen and Stockwell 1999) software packages to remove heave artifacts and adjust gains. Data were then imported into IHS Kingdom Suite software package (http://www.kingdom.ihs.com) for interpretation. Different acoustic signals were identified and mapped. A nominal sound velocity of 1500 m/s was used to convert two-way travel time (TWTT) to depth for all subbottom data. Results of the interpretation were loaded into ESRI ArcPro (http://www.esri.com) for comparison with CSEM results and additional analyses. The towed Chirp data are being archived at National Center for Environmental Information (NCEI) in standard envelope SEG-Y format. The digital object identifier (DOI) will be submitted to NOAA Office of Ocean Exploration (OER) once the archiving is completed.

R/V Sally Ride
Subbottom data were also collected on the R/V *Sally Ride* during cruise SR2301 using the hull-mounted Kongsberg SBP-29. The SBP-29 operates with a 2-9 kHz swept pulse. The data were exported in SEG-Y format and each file's header navigation was changed to UTM coordinates using MATLAB. Data were then imported into IHS Kingdom Suite software package (http://www.kingdom.ihs.com) for interpretation. A nominal sound velocity of 1500 m/s was used to convert two-way travel time (TWTT) to depth. These data will be archived on the Rolling Deck 2 Repository (https://doi.org/10.7284/909883).

CSEM
The CSEM data were collected aboard the R/V *Beyster*, utilizing the surface-towed porpoise system (Sherman et al. 2017) and deep-towed CUESI system. A total of twenty-five GB of CSEM data was collected over a linear survey distance of 120 km, spanning two cruises on the vessel. All CSEM data was recorded in SIO Marine EM Laboratory bin format, alongside real-time non-differential GPS data sampled every second for accuracy in positioning and seawater depth, conductivity, and temperature for reducing free model parameters (Table 5). Quality inspection was conducted on all data from all receivers to facilitate further processing.

Amplitude and phases of the CSEM response functions were extracted from the collected raw time-series data using a method detailed by Meyer et al. (2011). To increase the signal-to-noise ratio, the resulting transfer function estimates were stacked using an arithmetic mean to obtain the transfer function estimates for every selected stacking window along with an error estimate. This method yielded high quality amplitude and phase response data for all receivers as a function of position and frequency. Waveform-D was employed as the transmission waveform for all surface-towed data, owing to its ability to generate higher amplitude responses in specific harmonics, enabling data collection across a broad frequency range (Meyer et al. 2011). Amplitude and phase data from the surface-towed CSEM system were included in the inversion code for the first, third, seventh, and thirteenth harmonics, provided they exceeded the noise floor. However, due to the increased fundamental frequency in deep-towed data, a simpler square wave was utilized, and only the first and third harmonics for amplitude and phase data were integrated into the inversion code. A comparison of the amplitude associated with harmonics from Waveform-D (Myer et al., 2011) and a square wave is shown below. The fundamental frequency of both waveforms is 1 Hz and the peak output current is 1.



The modeling software utilized in this study was the publicly available, goal-oriented, adaptive, finite-element two-dimensional (2D) MARE2DEM inversion and modeling code developed by Key (2016). This code employs Occam's Inversion, a method that regularizes the inversion to attain the smoothest resistivity model fitting the data within a specified misfit (Constable et al. 1987). Prior to inclusion in the inversion as finite-length dipoles, the CSEM data underwent manual scrutiny for evident outliers and were subjected to a 2% error floor for surface-towed data and 5% error floor for deep-towed data. The seawater was incorporated as a fixed parameter in the starting models, utilizing conductivity data collected by the instruments and available bathymetric data. Therefore, the free inversion regions were reduced to the area below the seafloor and set to a uniform starting resistivity of 1 Ωm. Inversion parameter grids were constructed using 30-m-wide quadrilateral cells that increased in height with depth to mimic the loss of resolution of the EM method. Due to the adaptive nature of the MARE2DEM code, the computation mesh was allowed to fine where necessary to produce accurate responses. The resolution depth, as determined by the method of King and Constable (2023), was employed to restrict the depth of interpretation in the final models. All inversions were optimized to fit the data to a normalized root-mean-square of 1.

The resistive features identified within the 2D resistivity profiles resulting from the inversions were mapped for interpretation. These interpretation results were uploaded onto Google Earth and QGIS (https://qgis.org/en/site/) for comparison with subbottom results and additional analyses. The CSEM data is in the process of being archived on the SIO EM Laboratory website in standard SIO bin format, and the DOI will be submitted to NOAA OER upon the completion of archiving

ROV Imagery

ROV data were collected across five 12-hour shifts during 13 dives using MARE's Beagle ROV. During this time, 14 rock samples and 4 sediment samples were collected and 33.5 hours of video footage was captured via high-resolution forward and downward-facing cameras (totaling 572GBs of video footage). These videos also recorded pitch, roll, heading, depth, and temperature data. Initial navigation for the first six dives was severely restricted due to compatibility issues between the onboard HiPap and ROV software, preventing real-time navigation. However, navigation data was saved during these dives and later processed. Subsequent dives used newly coded navigation software from Dr. King, enabling live monitoring of the ROV's location.

Post-cruise navigation data collected by the HiPap and ROV were merged to generate comprehensive maps of the ROV dives. Utilizing Matlab software, the navigation data underwent review and integration into mapping tools like Google Earth, QGIS, and ESRI ArcGIS. Simultaneously, video footage was meticulously reviewed to pinpoint the exact times of sample collection, along with their corresponding latitude, longitude, and depth information.

A comprehensive ROV sample document was created, encompassing still photos of samples both onshore and in situ on the seafloor (Appendix C). The onshore and in situ images, merged with navigation data and detailed sample notes footage, was reviewed many times post-cruise to note seafloor characteristics in greater detail than what was possible during the actual dives.

Samples

Samples were labeled sequentially with the Scripps given cruise identifier of SR2023, the island near to where samples were collected (Anacapa), and type of sample (RK for rock or SD for sediment). For example, the first rock sample collected was named SR2023_Anacapa_RK1. They were placed in bags and labeled then placed in the ship freezer for transport. A samples log was created with sample name, dive #, date and time in both local and UTC, decimal degree latitude and longitude, probable material, and a general description. ROV images from each sample collection were saved with the data file and a sample log was created. Analysis files from the

XRF and XRD were generated into excel and include all instrumentation details and mineralogy and chemical analyses. XRD figures with labeled phases were also created. Data will be archived on FigShare and specimen logs on NCEI. Samples are housed at NHMLA and accessible for future research.

Global positioning system and GIS-derived spatial data for ship transects, sample locations, and paleolandscape modeling are stored as geotifs (TIF), ESRI shapefiles (SHP), and Google Earth files (KMZ). Figures generated for this project are stored in JPG and Adobe Illustrator file formats (i.e., PDF, AI). Datasets are provided in archive-ready, open-source, non-proprietary formats and are accompanied by ISO metadata with all mandatory elements completed and sufficient detail to permit their understanding and use by others. Post-processed datasets and reports generated by the project's researchers will have accompanying metadata, including descriptions of processing steps and quality assurance methods. The datasets generated during this study are archived, stewarded, and will be made discoverable and accessible to the public at multiple online repositories (Table 5). We will submit all publications generated from this project to the NOAA Institutional Repository after their acceptance.

Table 5. Major categories of project data collected and their archival status.

Data	Date Available	Archive Location	URL	Data Size	Data Format
Subbottom (EdgeTech 512i & SBP-29)	TBD*	*Rolling Deck 2 Repository *NCEI *NSF Marine Geoscience Data Center	https://doi.org/10.7284/909883 https://www.ngdc.noaa.gov/ http://www.marine-geo.org/index.php	7 GB	SEG-Y
CSEM (Porpoise & CUESI)	TBD*	*SIO EM laboratory *NSF Marine Geoscience Data Center	https://scripps.ucsd.edu/marine-em-laboratory http://www.marine-geo.org/index.php	25 GB	BIN
ROV Photos and Videos	TBD*	*NCEI	https://www.ngdc.noaa.gov/	572 GB	MP4
Sample Data	TBD*	*FigShare *NCEI	https://figshare.com https://www.ngdc.noaa.gov		

II.4. Findings

This project included geophysical data collection, ROV survey, and sample collection. Each of these phases provided opportunities for findings related to the broader goal of paleolandscape and paleoenvironmental reconstruction. The below sections will summarize the accomplishments and findings that have improved our understanding of the paleolandscape and paleoecology of this section of the Pacific's continental shelf.

II.4.a. Describe actual accomplishments and findings

II.4.a.i. Identification of Hydrocarbon Signals

A novel aspect of this research was inclusion of CSEM as part of the remote sensing efforts. CSEM measures the apparent resistivity of submerged units (i.e., pore fluid content, porosity, mineralogy etc.) and the output is sensitive to physical properties independent of those detected by acoustic methods. This can reduce the non-uniqueness of the anomalies and provide a separate dataset to consider for more targeted sampling. CSEM methods are frequently used to identify offshore hydrocarbon and can provide data on the geology and evolution of the landscape (Constable and Srnka 2007; Weitemeyer et al. 2017). Tar seeps, for instance, are not readily identifiable in Chirp data, particularly if the target is situated along a rocky substrate. These targets are recognizable in the CSEM output due to the uniquely high apparent resistivity of tar, whether an active or solidified deposit.

During the current effort, we used both a surface towed CSEM (Porpoise) and a deep-towed CSEM (CUESI), the latter recently developed by project collaborators King and Constable (King et al. 2022). The Porpoise is a small and low power surface-towed CSEM system that can be used effectively to map the seafloor geology to depths of 500 m below sea level. The system, illustrated in Figure 2, consists of an electromagnetic transmitter, four electric field receivers, and a dorsal device that collects water-conductivity and water-depth data. The horizontal electric dipole, four receivers (referred to as porpoises), and dorsal are towed on the surface of the water behind a vessel traveling between 2 and 4 knots on floating high molecular weight polyethylene rope. The frames of the receivers and dorsal are made from rigid plastic that is designed to slough off kelp or other ocean debris, to hold a rigid 2 meter dipole 0.67 m beneath the sea surface, and to provide mounting for a vertical GPS mast that doubles as a flashing beacon for better visibility to other vessels. To maximize sensitivity to the predicted geology, the receivers were separated by 100 meters creating a maximum source-receiver spacing of 400 meters and a total towed array length of 430 meters.

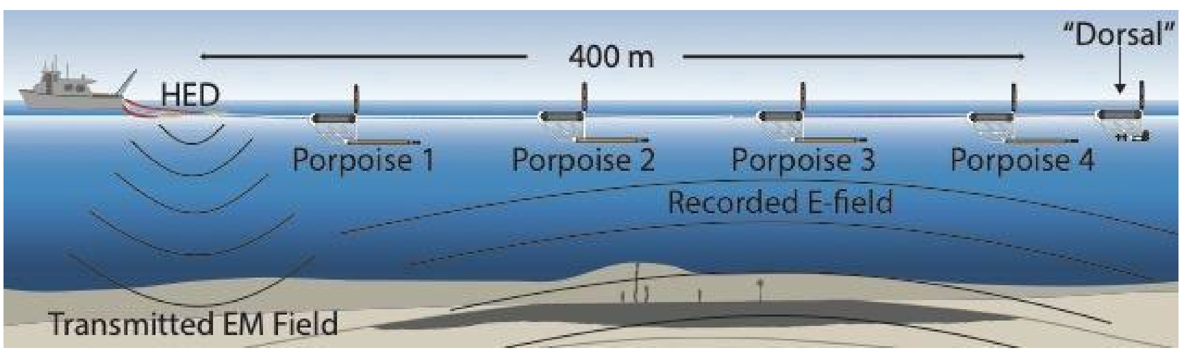


Figure 2. Schematic of Porpoise CSEM array used for this survey. Horizontal electric dipole is labeled here as 'HED'. Figure from King et al. 2022b.

The CUESI is an electromagnetic transmitter for CSEM imaging within the top 50 m of the subseafloor. The instrument uses external power to output a current up to 5 amps to a towfish 10 meters behind the transmitter (noted as Transmitter Electrode Dipole in Figure 3). Here, 5 amps are transmitted into the seawater using two 10 cm long, 1.5 cm diameter soft copper tubing held 2 m horizontally apart on a rigid frame for a source dipole moment up to 10 Am. Behind the dipole are two three-axis electric field receivers (noted as 3-axis Vulcan receivers in Figure 3) spaced 10 and 25 meters from the dipole respectively. All three towfish are positively buoyant (0.57 to 0.63 lbs) so that when a wire touches the seafloor, the towfish becomes neutrally buoyant at an altitude between 90 to 100 cm. CUESI is designed to double as a drop weight in continuous towing operations so that wave energy is not transferred to the array so towing altitude on the array remains consistent.

With the Porpoise and CUESI systems, we successfully identified numerous targets that appear positive for hydrocarbon, including targets that conform to what we would expect to see in the CSEM for an active or solidified tar seep. The targets were initially chosen as resistive anomalies on the seafloor and then rated as high to low priority dependent on if the anomalies display similar characteristics to marine hydrocarbon seeps (i.e. shape, migration pathway, spreading, local geology, historic records). While we identified a number of targets that we planned to explore during the ROV survey, the atmospheric storm during our January 2023 cruise made exploration possible only in the areas north of Anacapa Island. While our specific findings in the area north of Anacapa Island will be discussed in section II.4.a.iv, all areas identified for hydrocarbon and possible tar seeps will be discussed below. This will provide data for future investigation for tar seep identification and sampling. Each section will contain a fence plot of vertical resistivity, 2D vertical resistivity profiles of individual lines containing potential seeps, and possible seep locations plotted on a map. Navigational data are displayed in a table with priority ratings.

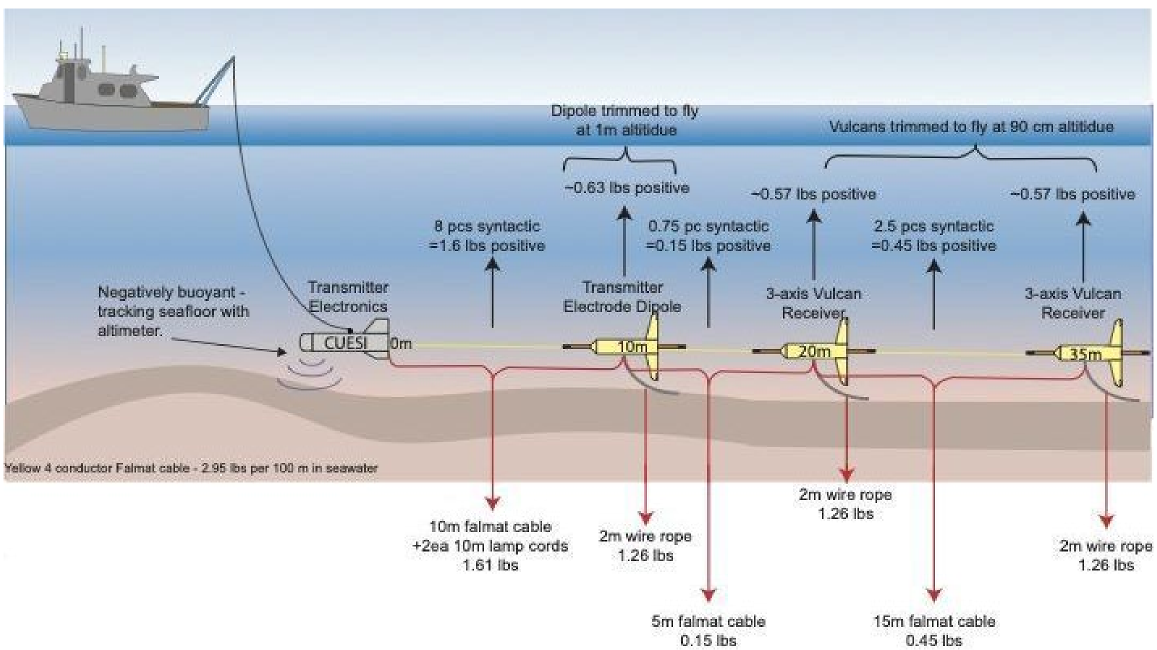


Figure 3. Schematic of CUESI array illustrating instrument spacing and buoyancy of the array. Figure from King 2022.

Point Conception

Fence Plot

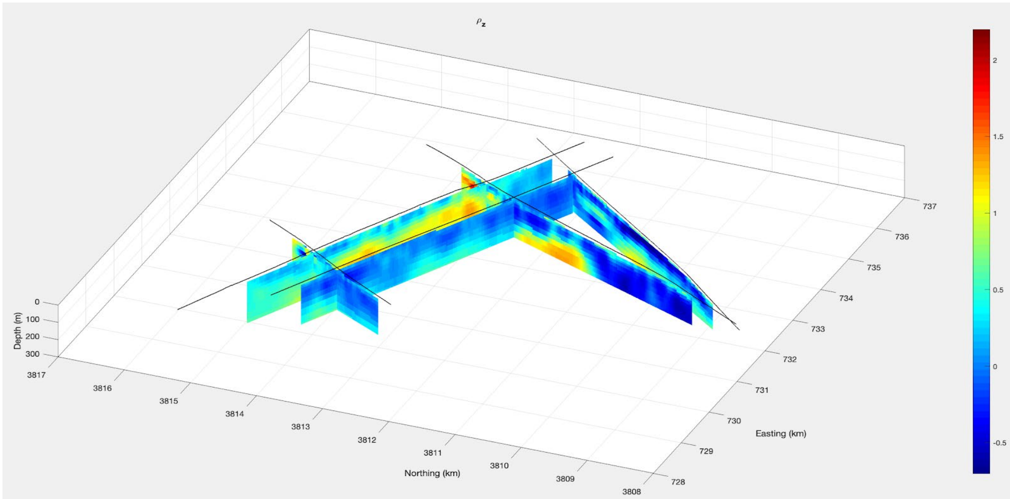


Figure 4: Resistivity fence diagram from Pt. Conception EM data. Color bar is log scale (log10(ohm m)). Figure by Roslynn King.

2D Vertical Resistivity Profiles

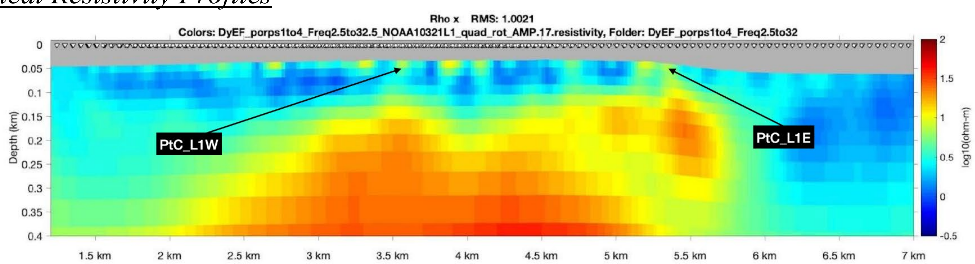


Figure 5: Pt. Conception 100321_Line1 vertical resistivity. Left is west, right is east. Two resistors at the seafloor are noteworthy: the eastern resistor (PtC_L1E, ~5.3 km along towline) appears to have a migration pathway below it and therefore may be active, the western resistor (PtC_L1W, ~3.5 km along towline) is above the shallowest point of a large resistor and may be 'fed' from this source. There are series of discrete resistors on the seafloor (which are also evident in the raw EM data) which could be discrete inactive or seasonally active asphalt mounds. These may also make good targets for sampling.

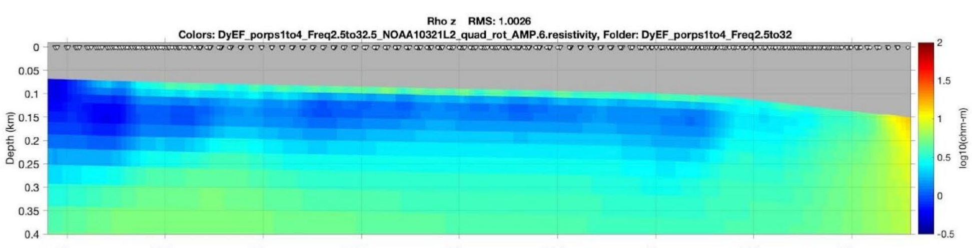


Figure 6: Pt. Conception 100321_Line2 vertical resistivity. Left is north, right is south. There are no notable resistors at the seafloor; however, at ~4.4 km along the towline where the slope angle steepens, there appears to be a change in seafloor resistivity. This coincides with noted pock marks on the seafloor so this change may be from hydrocarbons charging the sediment pore spaces and then being released into the water column.

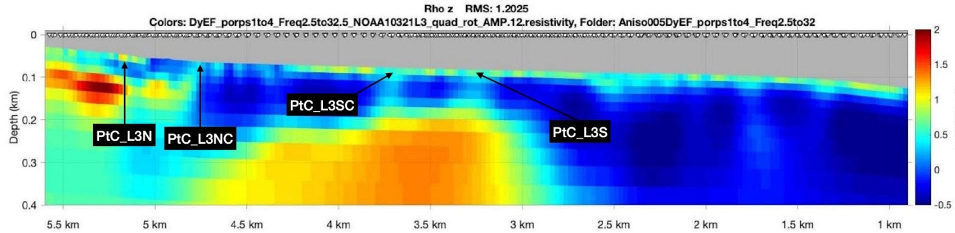


Figure 7: Pt. Conception 100321_Line3 vertical resistivity. Left is north, right is south. There are four seafloor resistors in this model that appear to have vertical hydrocarbon migration-like features below them. The farthest north resistor (PtC_L3N, ~5.2 km along the towpath) is collocated with an asphalt mound identified by the USGS. Slightly south at ~4.7km along the towpath, a seafloor resistor (PtC_L3NC) is noted above a strongly resistive vertical feature. This feature is also collocated with an identified asphalt mound at the seafloor. Centered above the 'dome-like' resistor between 3 to 4.5 km along the towpath are two minor seafloor resistors at ~3.25 km (PtC_L3S) and 3.75 km (PtC_L3SC) along the towpath. These seafloor resistors appear to have a migration pathway from the lower resistor; however, these two features are not collocated with any mounds at the seafloor from bathymetric data or previously identified hydrocarbon deposits.

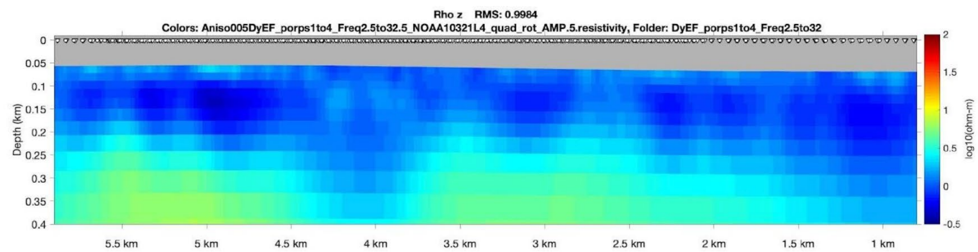


Figure 8: Pt. Conception 100321_Line4 vertical resistivity. Left is west, right is east. There are no strong resistors at the seafloor. However, there is some evidence of fluid flow at ~5 km along the towline and between ~2.46 km and 2.8 km along the towline.

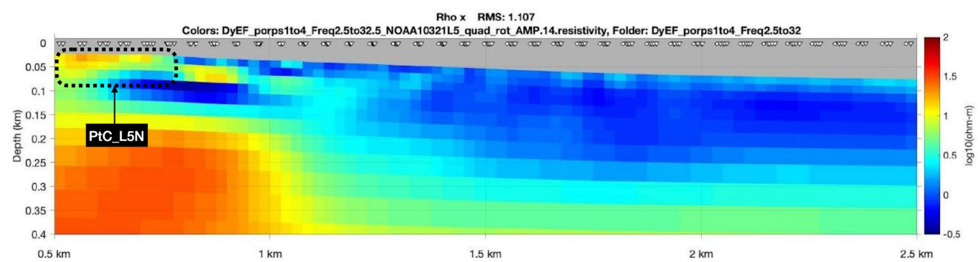


Figure 9: Pt. Conception 100321_Line5 vertical resistivity. Left is north, right is south. One major seafloor resistor is noted on the northern end of this survey line (PtC_L5N). This seafloor resistor is collocated with a large asphalt mound identified by the USGS. Due to the depth of this feature, it may be difficult to sample.

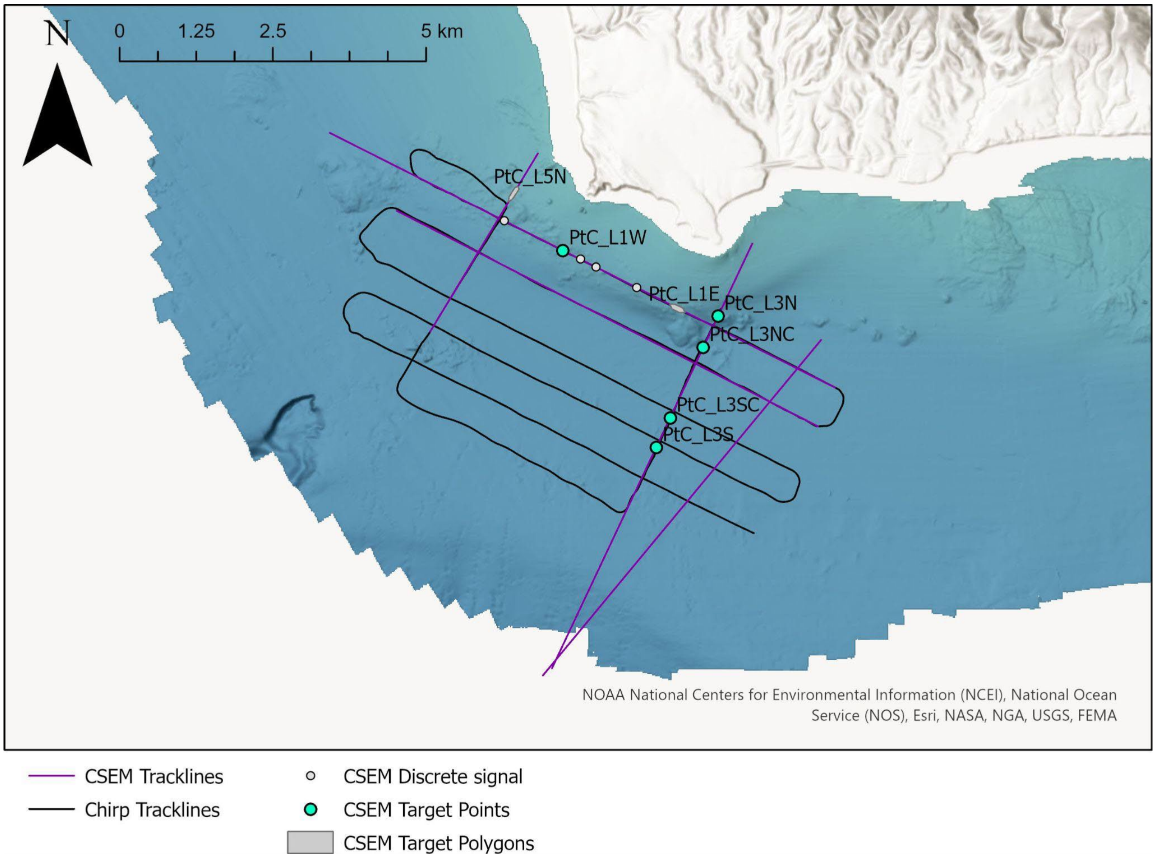


Figure 10. Pt. Conception map of survey lines and seafloor resistors.

Table 6. Potential targets off Pt. Conception

Location	Name on Map	Priority	Depth (m)	Description
NOAA100321_ Line1Wresist	PtC_L1W	low	~32	This seafloor resistor is above the shallowest point of a large resistor which may be 'feeding' the seep. This feature is also collocated with asphalt deposits identified in the local geologic map.
NOAA100321_ Line1Eresist	PtC_L1E	high	35-41	The seafloor resistor appears to have a migration pathway below it and therefore may be active. This feature is collocated with asphalt deposits identified in the local geologic map.
NOAA100321_ Line5Nresist	PtC_L5N	high	23-27	The seafloor resistor is collocated with a large asphalt mound identified by the USGS. This feature also appears to have a migration pathway below it and therefore may be active. Due to the depth of this feature, it may be difficult to sample.

Location	Name on Map	Priority	Depth (m)	Description
NOAA100321_ Line3Nresist	PtC_L3N	high	~43	The seafloor resistor is collocated with an asphalt mound identified by the USGS. This feature also appears to have a migration pathway below it and therefore may be active. This feature also has a very similar geometry to the seafloor resistor encountered in line 5.
NOAA100321_ Line3NCresisit	PTC_L3NC	medium	~63	The seafloor resistor is noted above a strongly resistive vertical feature. This feature is also collocated with an identified asphalt mound at the seafloor.
NOAA100321_ Line3Cresist	PtC_L3SC	low	~79	Centered above the 'dome-like' resistor between 3 to 4.5 km along the towpath are two minor seafloor resistors at ~3.25 km and 3.75 km along the towpath. This resistor is the northern of the two and it appears to have a migration pathway from the lower resistor; however, this feature is not collocated with any mounds at the seafloor from bathymetric data or previously identified hydrocarbon deposits.
NOAA100321_ Line3Sresist	PtC_L3S	low	~83	Centered above the 'dome-like' resistor between 3 to 4.5 km along the towpath are two minor seafloor resistors at ~3.25 km and 3.75 km along the towpath. This resistor is the southern of the two and it appears to have a migration pathway from the lower resistor; however, this feature is not collocated with any mounds at the seafloor from bathymetric data or previously identified hydrocarbon deposits.

San Miguel Island

Fence Plot

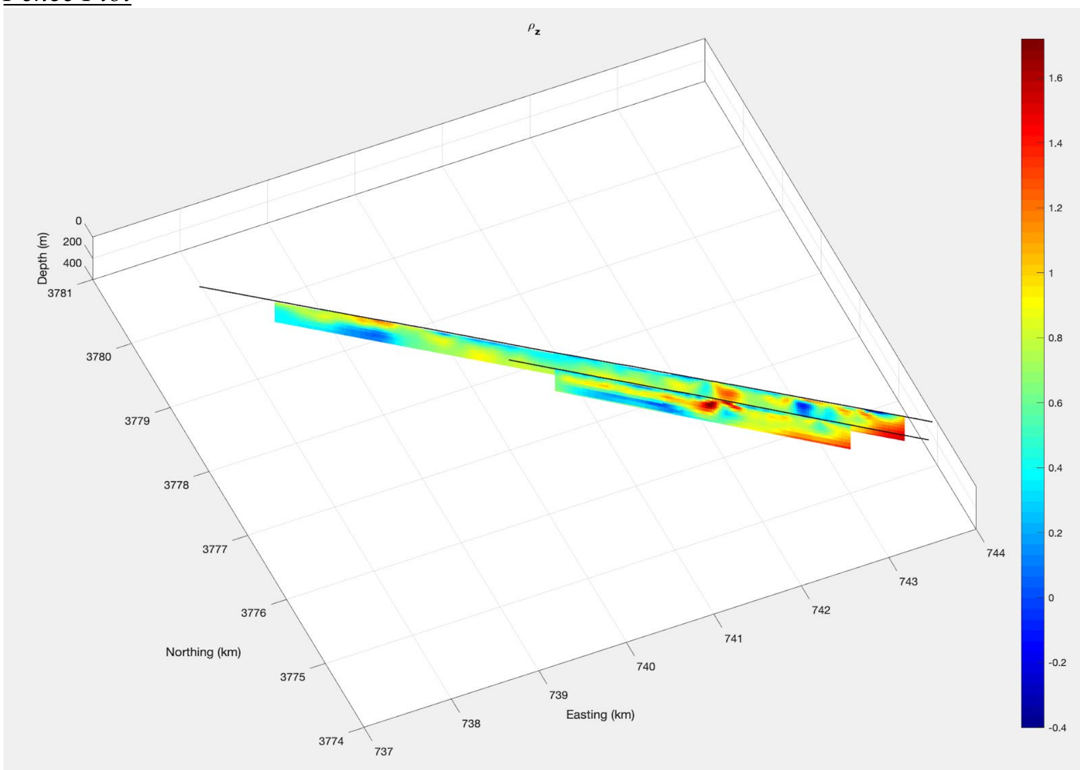


Figure 11: Resistivity fence diagram from San Miguel CSEM data. Color bar is log scale (log10(ohm m)).

2D Vertical Resistivity Profiles

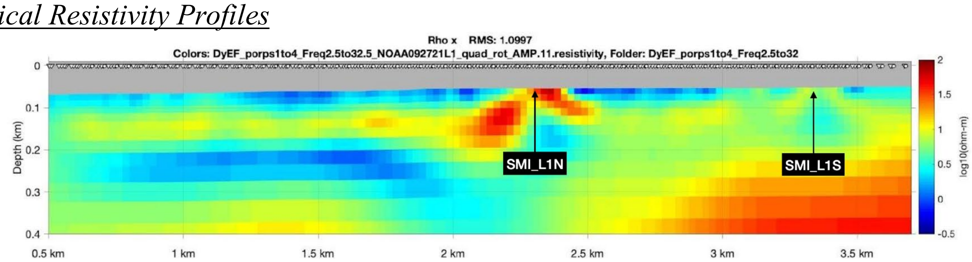


Figure 12: NOAA092721 Line 1 (southern line) vertical resistivity profile. West to left, east to right. Two main resistors are present at the seafloor (SMI-L1N & SMI_L1S).

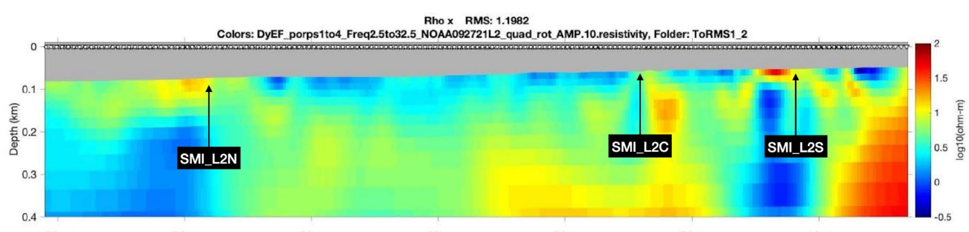


Figure 13: NOAA092721 Line 2 (northern line) vertical resistivity profile. West to left, east to right. Three main resistors are present at the seafloor (SMI_L2N, SMI_L2C & SMI-L2S). This profile indicates vertical flow of hydrocarbons below the two eastern/southern seafloor resistors.

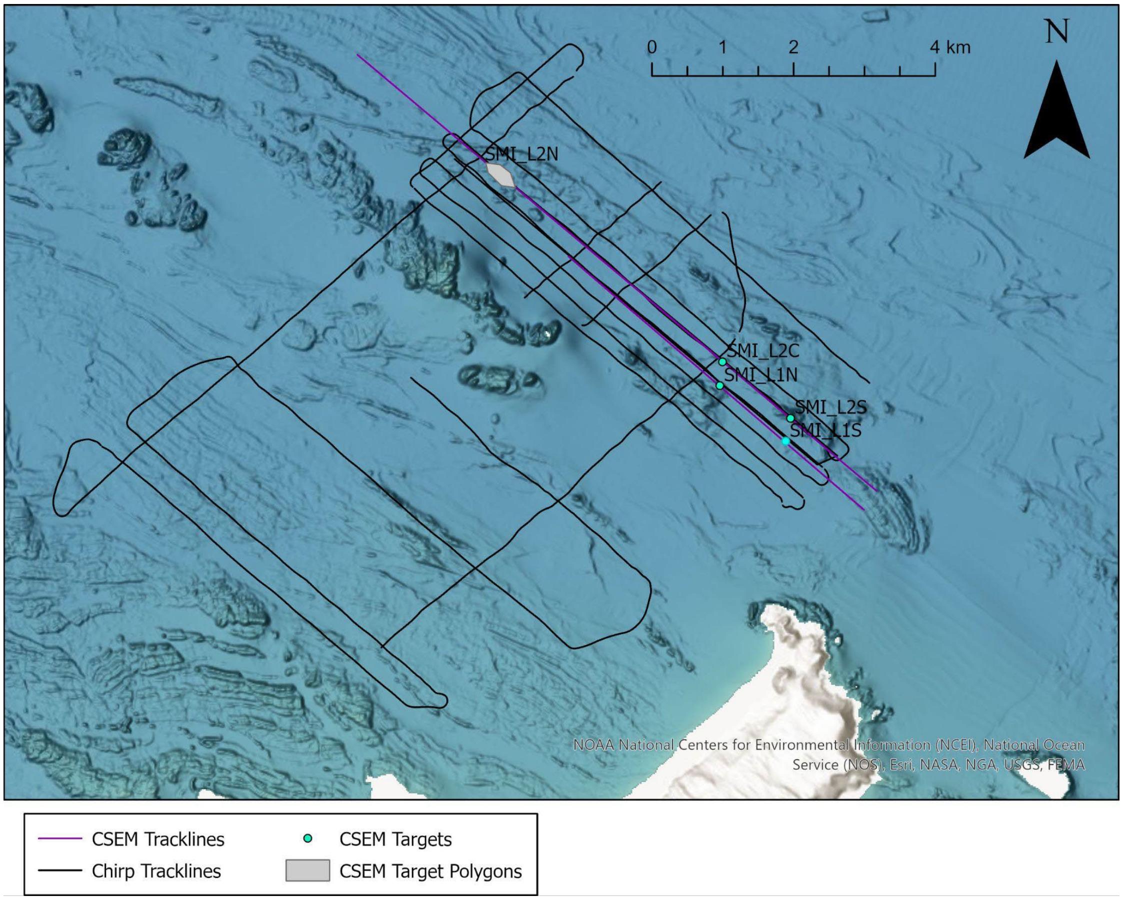


Figure 14. San Miguel map of survey lines and seafloor resistors.

Table 7. Potential targets off San Miguel Island

Location	Name on Map	Priority	Depth (m)	Description
NOAA092721 _Line1	SMI_L1S	Medium	54	Unidentified potential seep. This seep likely has ties to the buried source of hydrocarbons (see line 2 for vertical resistor); high chance of active seeping. Additionally, this seep is highly resistive and is also encountered in NOAA092721_Line 2.
NOAA092721 _Line1	SMI_L1N	High	52	Unidentified potential seep. Appears to be strongly connected to buried source of hydrocarbons. Will most likely be active. Collocated with mounds on the seafloor. Note: ROV drop should be on Line 2 as this is where the mounds have been mapped.
NOAA092721 _Line2	SMI_L2N	Low	75	Resistor at seafloor which appears to be near a lateral change resistivity (possible fault). May have hydrocarbon migration along fault and could be active. Could be lithological in origin hence the low priority rating.

Location	Name on Map	Priority	Depth (m)	Description
NOAA092721 _Line2	SMI_L2S	Medium	53	Unidentified potential seep. This seep likely has ties to the buried source of hydrocarbons; high chance of active seeping. Additionally, this seep is highly resistive and is also encountered in NOAA092721_Line 1.
NOAA092721 _Line2	SMI_L2C	High	59	Unidentified potential seep. Appears to be strongly connected to buried sources of hydrocarbons. Will most likely be active. Collocated with mounds on the seafloor. Note: ROV drop should be on Line 2 as this is where the mounds have been mapped.

Anacapa Island

Fence plot

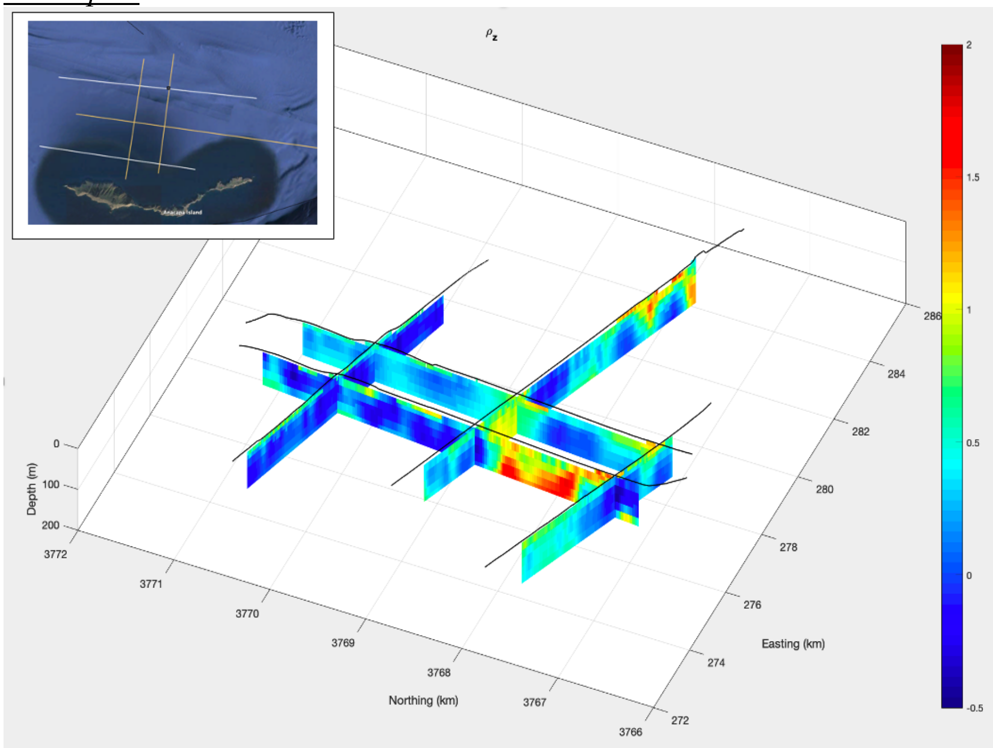


Figure 15: Resistivity fence diagram from Anacapa Island CSEM data. Color bar is log scale (log10(ohm m)).

2D Vertical Resistivity Profiles

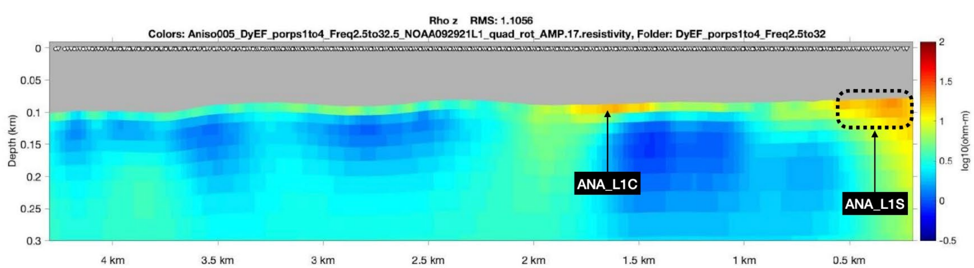


Figure 16: Vertical resistivity profile of line NOAA092921_Line1. North to left, south to right. Two resistors at the seafloor are noted: a central resistor (ANA_L1C, ~1.7 km along towline) and a wedge shaped resistor (ANA_L1S, ~0 to 0.5 km along the towline).

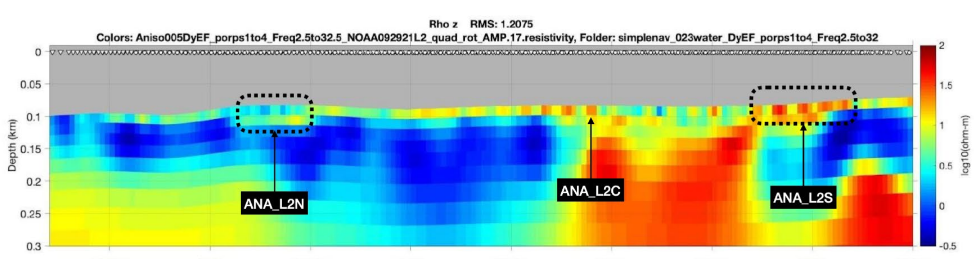


Figure 17: Vertical resistivity profile of line NOAA092921_Line2. North to left, south to right. Three resistors at the seafloor are noted (ANA_L2N, ANA_L2C & ANA_L2S).

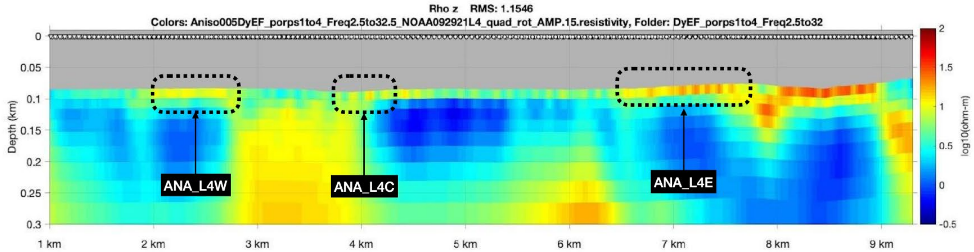


Figure 18: Vertical resistivity profile of line NOAA092921_Line4. West to left, east to right. Three resistors at the seafloor are noted (ANA L4W, ANA_L4C & ANA-L4E).

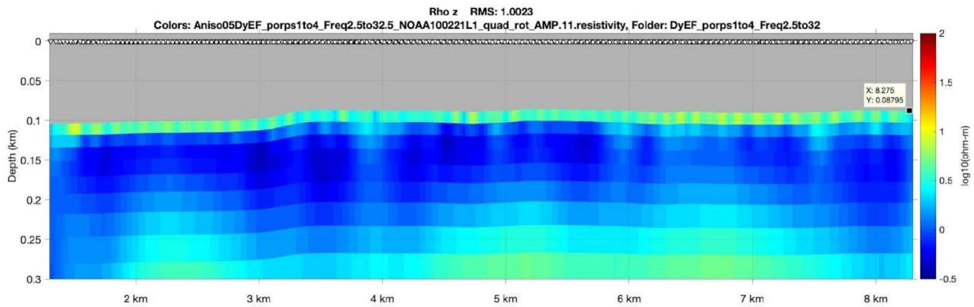


Figure 19: Vertical resistivity profile of line NOAA100221_Line1 (northern line). West to left, east to right. No seafloor resistors are noted.

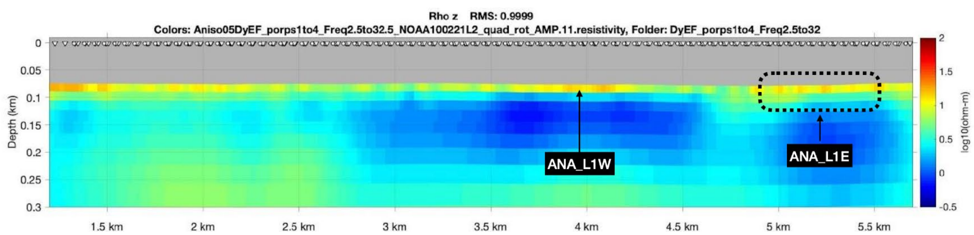


Figure 20: Vertical resistivity profile of line NOAA100221_Line2 (southern line). West to left, east to right. Two seafloor resistors are noted (ANA_L1W & ANA_L1E) which correspond to resistors encountered in lines NOAA092921_Line1 and NOAA092921_Line2.

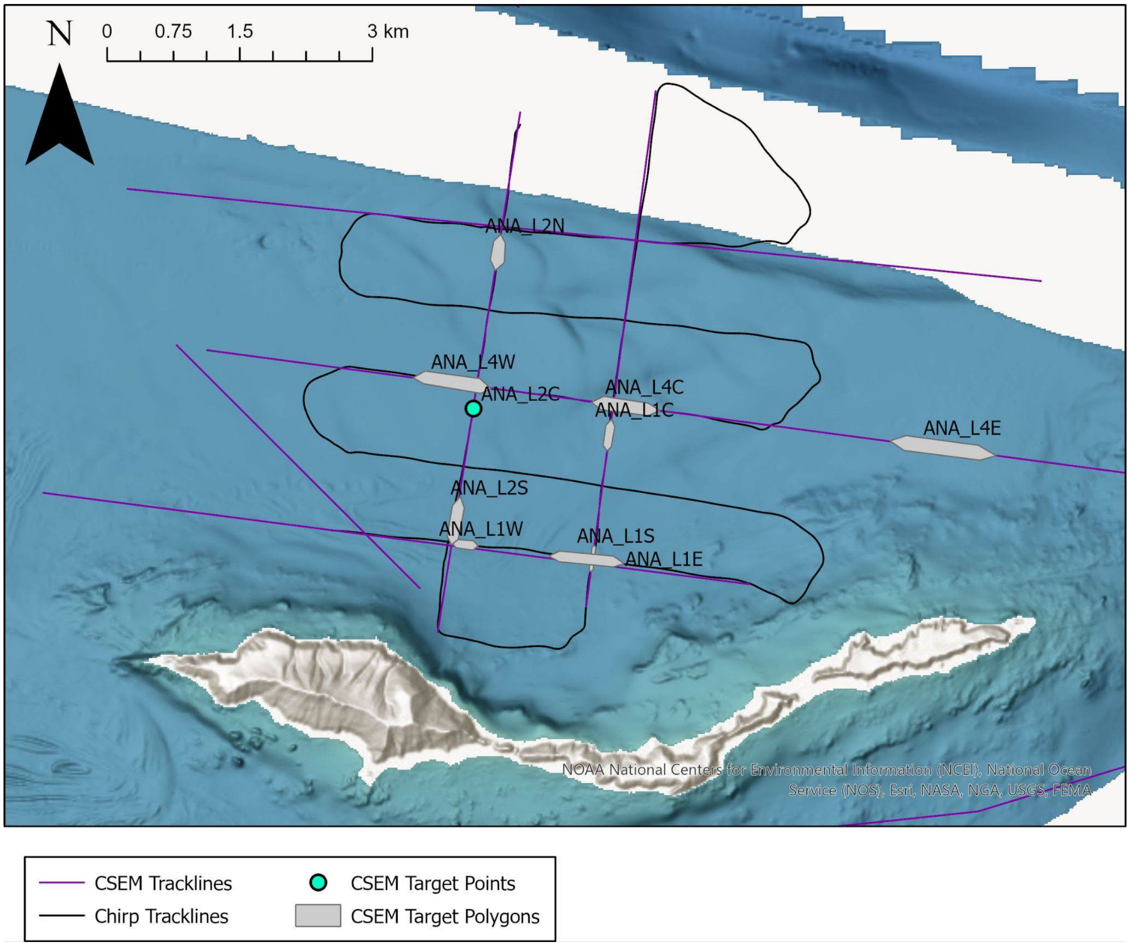


Figure 21. Anacapa Island map of survey lines and seafloor resistors.

Table 8. Potential targets off Anacapa Island

Location	Name on Map	Priority	Depth (m)	Description
NOAA092921_ Line1 (southern)	ANA_L1S	Low	78-81	Most likely lithological in origin as this is close to the island (which is volcanic/resistive) and does not appear to have seep-like characteristics.
NOAA092921_ Line1 (central)	ANA_L1C	Medium	~82	Seafloor resistor with no obvious source within this inversion; however, line NOAA092921_L4 suggests vertical fluid flow slightly west of and below this resistor.
NOAA092921_ Line2 (north)	ANA_L2N	Low	82-86	Geometry of resistor at seafloor suggests fluid flow (vertical and then spreading at seafloor). There could be a seep here; however, the resistivity of the feature is low which could mean that if there are hydrocarbons, they may be diffuse or well mixed with seafloor sediment.

Location	Name on Map	Priority	Depth (m)	Description
NOAA092921_Line2 (central)	ANA_L2C	High	82	Geometry of resistor at seafloor suggests fluid flow (vertical and then spreading at seafloor). Strong resistive signature below seafloor anomaly. The seafloor resistivity is moderate indicating that the hydrocarbons may be mixed with sediment or in small quantities (see bulk resistivity and smoothing algorithm).
NOAA092921_Line2 (south)	ANA_L2S	High	78-81	Geometry of resistor at seafloor suggests fluid flow (vertical and then spreading at seafloor). Strong resistive signature below seafloor anomaly. The seafloor resistivity is strong (>50 ohm m) indicating that a hydrocarbon lens or mound may be at the seafloor.
NOAA092921_Line4 (west)	ANA_L4W	High	~82	Geometry of resistor at seafloor suggests fluid flow (vertical and then spreading at seafloor). Strong resistive signature below seafloor anomaly. The seafloor resistivity is moderate indicating that the hydrocarbons may be mixed with sediment. The seafloor resistor is collocated with the seafloor resistor encountered in NOAA092921_Line2 (central).
NOAA092921_Line4 (central)	ANA_L4C	Medium	~82	Seafloor resistor encountered in NOAA092921_Line1, but from another perspective. This inversion indicates a possible path for hydrocarbons to the seafloor.
NOAA092921_Line4 (east)	ANA_L4E	Low	79-80	The geometry of this seafloor resistor suggests a lithological origin.
NOAA100221_Line1 (west)	ANA_L1W	High	~74	Geometry of resistor at seafloor suggests fluid flow (vertical and then spreading at seafloor). Strong resistive signature below seafloor anomaly.
NOAA10221_Line1 (east)	ANA_L1E	Low	~79	Most likely lithological in origin as this is close to the island (which is volcanic/resistive) and does not appear to have seep-like geometry.

Coal Oil Point (Goleta)
The data from Coal Oil Point include some data collected on previous research cruises not funded with the current NOAA grant. These data were, however, analyzed and used with the current research to consider ROV targets, so are included here.

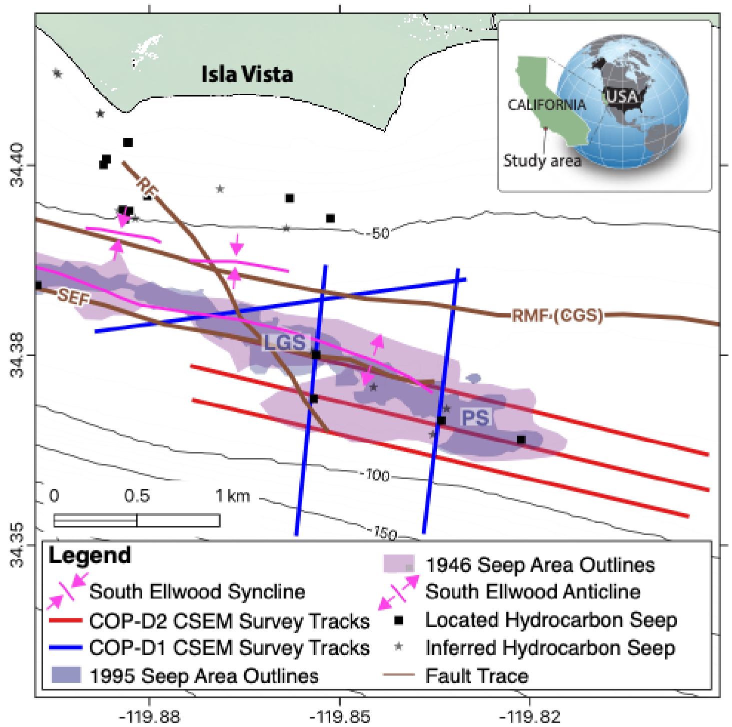


Figure 22: Coal Oil Point seep field area offshore Isla Vista located within Santa Barbara County, California. COP-D1 CSEM survey tracks (red lines) represent locations of data collected in January 2019. COP-D2 CSEM survey tracks (blue lines) represent locations of data collected in May 2021. Survey track lines were chosen based on proximity to seep area outlined from 1995 seep gas spatial distributions by Hornafius et al. (1996) and inferred and located seep locations identified and defined by the USGS (Lorenson et al. 2009). The seep area outlined from 1946 gas and oil distributions is by Fischer (1978). La Goleta seep field is labeled LGS and Patch Seep is labeled PS (all seep names are informal). Finally, South Ellwood Anticline, South Ellwood Syncline, and fault locations from Leifer et al. 2010 and California Geological Survey are plotted: RF - Rudder Fault, RMF (CGS) - Red Mountain Fault trace by California Geological Survey (USGS 2006), SEF – South Ellwood Fault. Water depth contours are marked in black.

Fence plot

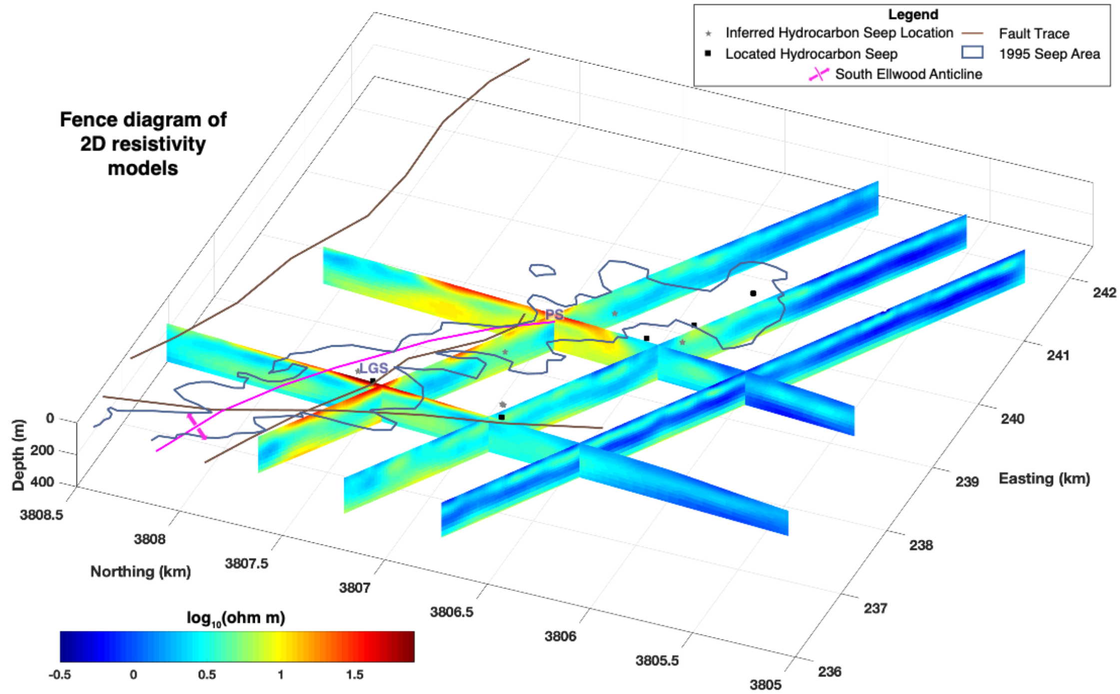


Figure 23: Fence plot of 2D resistivity models over La Goleta MHS field (labeled here as 'LGS') and Patch Seep (labeled here as 'PS'); CSEM survey lines and dates of collection are also shown in Figure 22. Dark blue lines indicate areal extent of seep gas distributions from Hornafius et al. (1996). Black squares indicate located seeps, and grey stars indicate the inferred location of seeps identified and defined by the USGS (Lorenson et al. 2009). Brown lines indicate the surface locations of the Rudder Fault, South Ellwood Fault (Leifer et al. 2010), and Red Mountain Fault (USGS 2006). Warm colors indicate high resistivity, inferred to be hydrocarbons. Coordinates in fence plot are UTM – Zone 11.

2D Vertical Resistivity Profiles

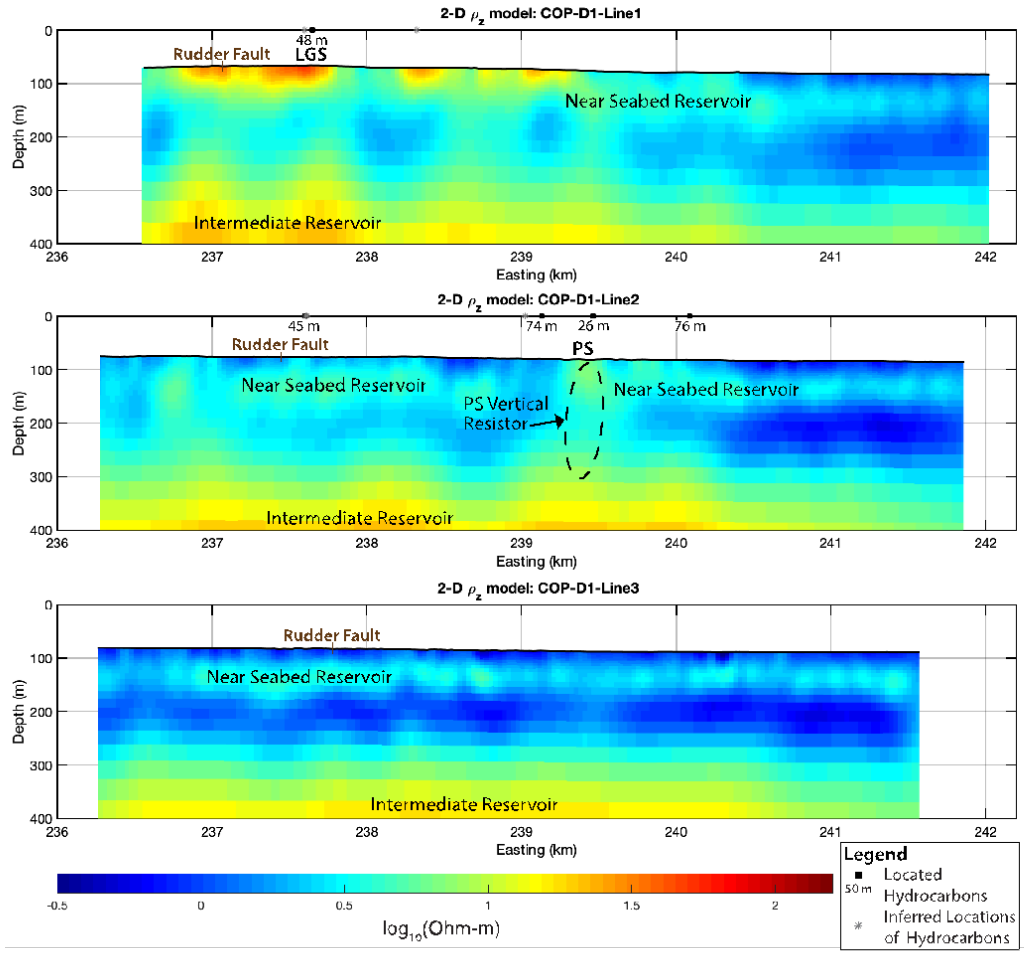


Figure 24: 2D Resistivity Models of COP-D1 Lines 1 through 3 plotted with approximate locations of major seepage associated with La Goleta MHS Field (LGS) and Patch Seep (PD). Also plotted are locations of known and inferred seep locations as identified and defined by the USGS (Lorenson et al. 2009) with crossline distances to known hydrocarbon seep locations indicated. See Figure 23 for plan view of model locations. The surface trace of the Rudder Fault is plotted in brown. Here, depth refers to meters below sea-level.

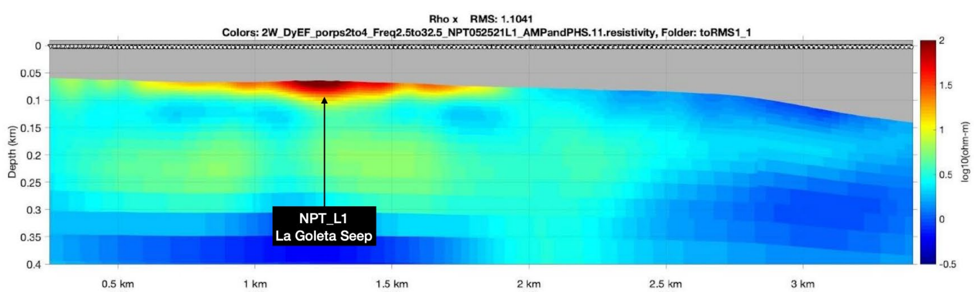


Figure 25: NPT_Line1. North to left, south to right. The main resistive (>1.5 log10(ohm m)) anomaly at the seafloor is collocated with the informally named 'La Goleta' seep. This area has been noted to be actively seeping oil from USGS reports.

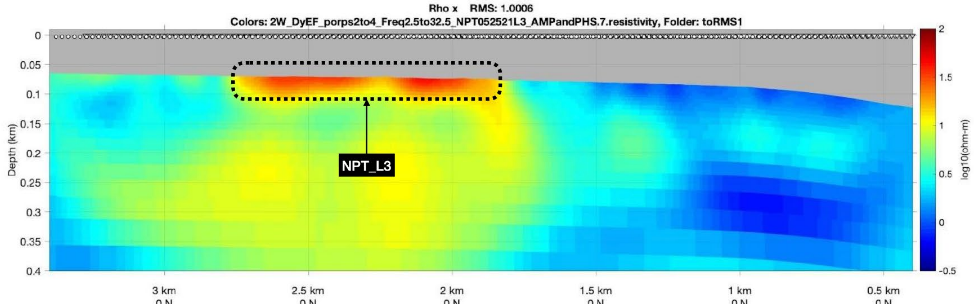


Figure 26: NPT_Line3. North to left, south to right. Resistor is more diffuse at the seafloor (or not as intensely resistive). The seafloor resistor appears to be ‘fed’ by a vertical feature ~1.8 km along the towline. This signal may be from seeping gas.

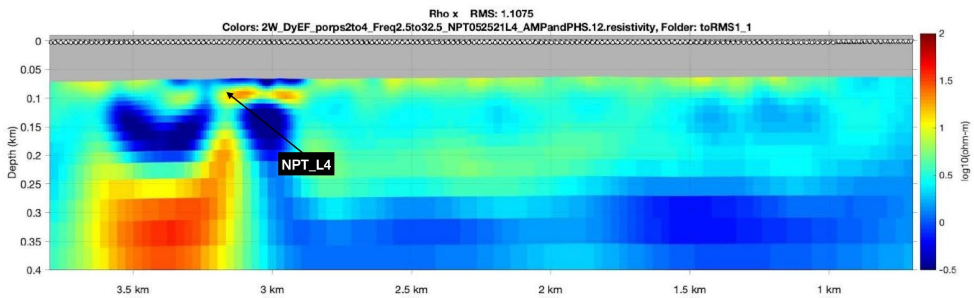


Figure 27: NPT_Line4. West is left, east is right. Resistor may continue to the seafloor. The resistor at ~3.25 km along towline is collocated with seafloor mound in the google earth bathymetry. High priority as this is an unidentified seep and has a mound at the seafloor. This may be an active seep site as there is a vertical resistor directly below the mound.

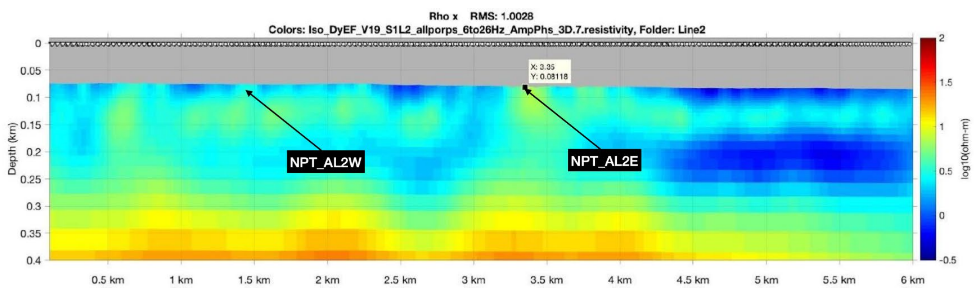


Figure 28: Amigo Line 2. West to the left, east to the right. There are two potential targets on this line: a western resistor (NPT_AL2W) ~1.4 km along the towline and an eastern resistor (NPT_AL2E) ~3.35 km along the towline. The western resistor is collocated with tar collected by the USGS in the water column. The eastern resistor is collocated with the patch seep.

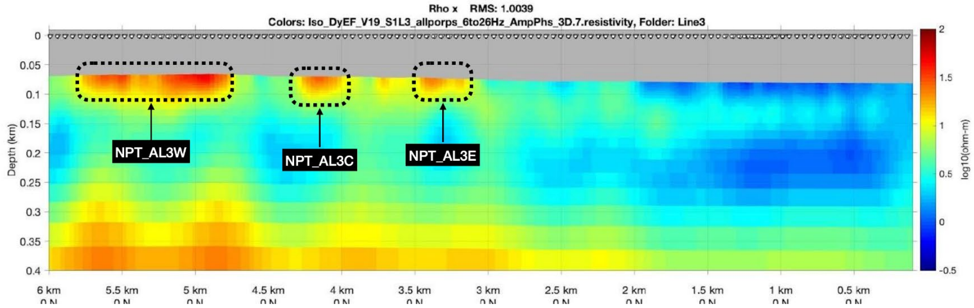


Figure 29: Amigo Line 3. West to left, east to right. Three potential targets on this line. Western resistor between 4.7 km to 5.7 km is highest priority as it is collocated with La Goleta Seep and may be active (NPT_AL3W). The eastern resistor (NPT_AL3E) between 3.2 and 3.5 km along towline is moderate priority as it appears to have a vertical resistor 'feeding' the system. A central resistor (NPT_AL3C) is low priority.

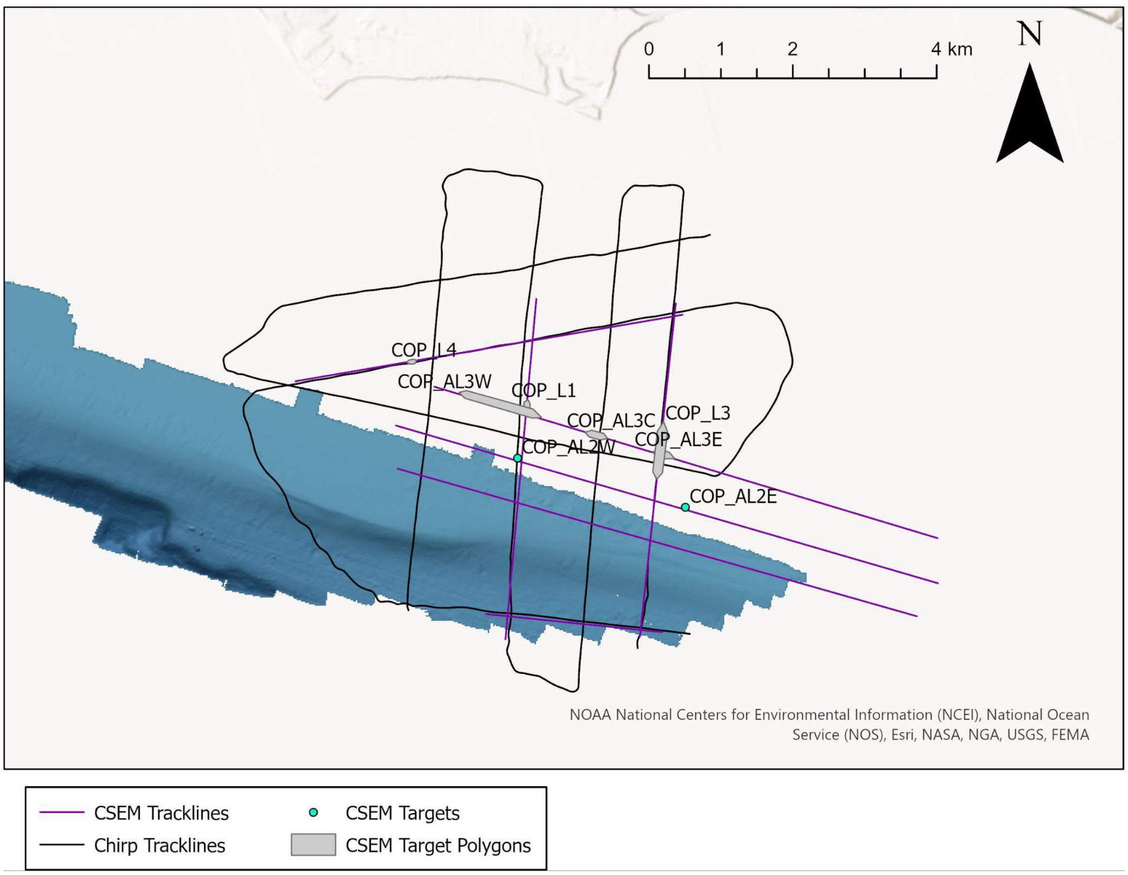


Figure 30. Coal Oil Point (Goleta) map of survey lines and seafloor resistors

Table 9. Potential Targets at Coal Oil Point

Location	Name on Map	Priority	Depth (m)	Description
NPT_Line1	COP_L1	High	66	Seafloor resistivity is high, vertical feature appears below seafloor anomaly, and geometry is consistent with that of marine hydrocarbon seeps. This seep is collocated with La Goleta Seep.

Location	Name on Map	Priority	Depth (m)	Description
NPT_Line3	COP_L3	Medium	70-77	Seafloor resistivity is moderate, but does not appear to have any hydrocarbon migration pathway below it. This feature may be diffuse hydrocarbons at the seafloor.
NPT_Line4	COP_L4	High	67	Resistive feature at seafloor is collocated with seafloor mound in the google earth bathymetry. High priority as this is an unidentified seep and has a mound at the seafloor. This may be an active seep site as there is a vertical resistor directly below the mound.
Amigo_Line2 _WResist	COP_AL2 W	Low	76	The seafloor resistor is collocated with tar collected by the USGS in the water column.
Amigo_Line2 _EResist	COP_AL2E	Low	80	The seafloor resistor is collocated with the active patch seep, but intensity of resistor indicates limited amounts of hydrocarbons.
Amigo_Line3 _WResist	COP_AL3 W	High	66	Seafloor resistivity is high, vertical feature appears below seafloor anomaly, and geometry is consistent with that of marine hydrocarbon seeps. This seep is collocated with La Goleta Seep.
Amigo_Line3 _CResist	COP_AL3C	Low	69	Moderately resistive seafloor anomaly with no obvious migration pathway for hydrocarbons to reach the seafloor. This site may be inactive.
Amigo_Line3 _EResist	COP_AL3E	Medium	73	Seafloor resistivity is moderate, but does not appear to have any hydrocarbon migration pathway below it. This feature may be diffuse hydrocarbons at the seafloor.

II.4.a.ii. Effectiveness of CUESI

Sea-level rise following the LGM (~20 kya) resulted in the submergence of paleochannels, tar seeps, and archaeological sites on continental shelves. The distribution of these sites is important for archaeological research, offshore infrastructure development, and environmental hazard assessment. Identification of these sites is typically attempted using a combination of side scan and subbottom sonar remote sensing methods, followed by evaluation of hundreds of resulting images to select targets for sampling. Our recent research suggests that the process of narrowing down targets for sampling may be facilitated by incorporating CSEM equipment into the remote sensing surveys. Using MARE2DEM software, we previously developed a model to test CSEM effectiveness for identifying shell midden deposits, tar seeps, and paleochannels. Results indicated that a modified bottom-towed CSEM system can resolve all three targets. This bottom-towed system (CUESI) was developed by Dr. King at the SIO Marine EM lab and was tested on the current project.

During its development, the CUESI system was tested over existing sediment core locations and regions previously surveyed with a subbottom profiler and the surface-towed CSEM system of Sherman et. al. (2017) in several areas offshore Southern California. The case studies presented here are limited to the two regions highlighted in Figure 31. Coal Oil Point is a known location of multiple marine hydrocarbon seeps. Hydrocarbons are highly resistive making this region an attractive area to initially test the sensitivity of the CUESI system to significant changes in resistivity within the seafloor. Additionally, this region has been previously surveyed using the more established surface-towed CSEM system of Sherman et al. (2017) so comparison between datasets is possible.

The Channel Islands were chosen as a test site for the CUESI system as sediment core, acoustic reflection, and CSEM data are available in this region. Using the core data, the CUESI system could be tested for its ability to resolve porosity changes within the shallow seafloor. The acoustic reflection profiles provide context for the core locations and lateral constraints on the local geology.

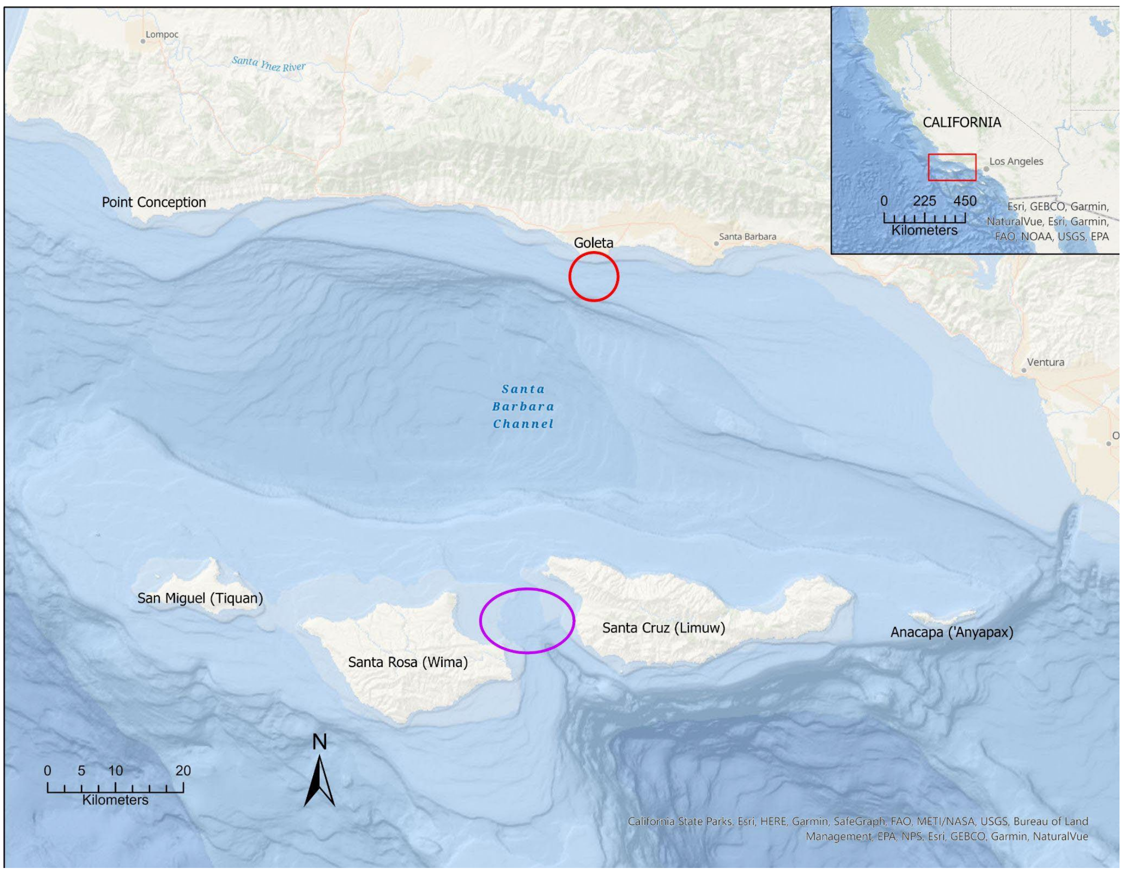


Figure 31: Case study survey areas offshore Southern California. The red circle marks the location of the Coal Oil Point seep field south of Santa Barbara and the purple circle marks the location of the study area between Santa Rosa Island and Santa Cruz Island within Channel Islands National Marine Sanctuary.

CUESI Sensitivity to Seafloor Resistors – Coal Oil Point

In May 2021, the CUESI system underwent its initial test at the Coal Oil Point seep field. This trial aimed to assess system functionality, towing performance, and sensitivity to known resistive features. Due to being in its early development stage, limited navigational constraints and sparse data collection were encountered.

The Coal Oil Seep field had prior imaging via a surface-towed CSEM system, providing well-defined locations of resistive features before the CUESI survey. Figure 32 compares amplitude data from the CUESI survey to a resistivity profile of an active seep. The red feature indicates interpreted hydrocarbons on the seafloor, while blues signify typical marine sediment with a resistivity between 1 to 2 Ωm. The top panel of Figure 32 shows amplitude responses stacked in 10-second windows from the third towfish. Higher amplitude responses over the seep field, correlating with resistive hydrocarbons, align with expectations.

The recorded amplitude responses by the CUESI system, despite insufficient navigational data for pseudosection creation, displayed promising correlation between amplitude response and seafloor resistors. This correlation suggested the system's potential in detecting changes in resistivity, prompting further development.

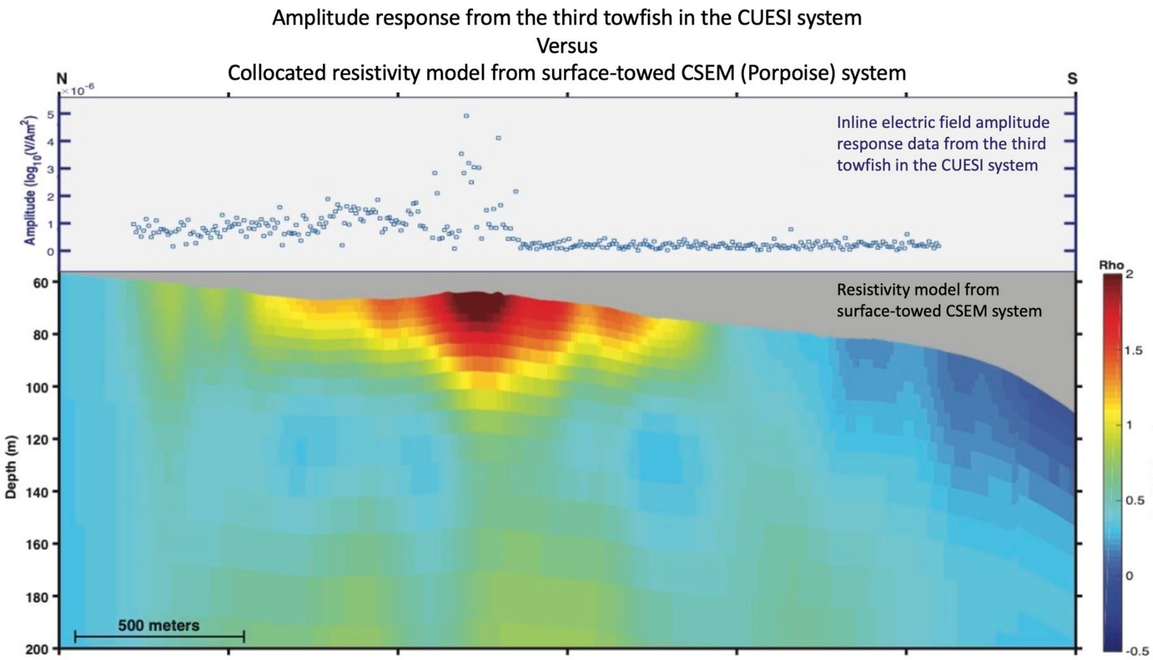


Figure 32: Comparison between amplitude data from the CUESI system and a resistivity profile generated from surface-towed CSEM data over an active seep within the Coal Oil Point seep field. The top panel is the inline amplitude data from the third towfish in the CUESI array. The bottom panel is a collocated resistivity profile from King et al. (2022).

CUESI comparison to core data – Channel Islands National Marine Sanctuary

Following the initial functionality tests of the CUESI system, the array was moved to the waters between Santa Cruz and Santa Rosa Islands in the Channel Islands National Marine Sanctuary. Here, the CUESI system was used to survey several areas where core data were collected on a previous cruise (BOEM cooperative agreement M15AC00012). Due to sea-conditions, surveying time was limited and target areas were reduced to a few locations within the survey area mapped in Figure 31. During the survey, a 25 Hz, 2.5 Amp square wave was transmitted on a 2 meter horizontal dipole. The inline electric time series measured on the second and third towfish during these surveys was Fourier transformed and stacked into 10 second windows. Stacking the data provides error estimates as well as increasing the signal to noise ratio. The first and third harmonics from the transmitted 25 Hz square wave were included in the processing.

From these surveys, pseudosections were generated using the inline electric field data from the second and third towfish. Pseudosections use the navigation data collected from each towfish and the water depth and conductivity collected by CUESI during the survey. Forward solutions are calculated from 1D models that include the water depth and seawater conductivity underlain by halfspaces ranging from 0.1 to 1000 Ωm. Apparent resistivity values are obtained by interpolating between the forward solutions and each value of the stacked amplitude data. The general depth of each apparent resistivity value is calculated from the approximate skin depth of each frequency used and the source receiver offset. Each apparent resistivity value can then be represented by a pixel with location data and these pixels are combined to create pseudosections. Pseudosections are good indicators of lateral changes in resistivity, but have been noted to have limited ability to determine actual depths to features (Weitemeyer et al. 2006).

Pseudosections generated from data collected over two core locations are shown in Figure 33. Here, the top pseudosection was created from data collected while targeting core CI-VC-B4. This core was initially collected to target a mound identified in acoustic reflection data shown in Figure 34. The core is more porous than the surrounding sediment as it contains abundant intact and fragmented shells which have created voids in the sediment. To test the ability of the CUESI system to detect changes in seafloor porosity, the apparent resistivity values must first be converted into porosity values using the Winsauer et al. (1952) Humble formula (1), which is commonly used for unconsolidated sediments or loose formations such as marine sands (El-khatib 1997). Here, resistivity and pore fluids are related using the Humble formula which is given by the equation:

$$\rho_o = a\rho_f \phi^{-m} \tag{1}$$

where ρ_o is the bulk resistivity of the water-saturated material, ρ_f is the resistivity of the pore fluids, ϕ is the porosity of the material, m is the cementation factor, and a is the ‘tortuosity’ or ‘lithology’ parameter. The Humble formula uses a cementation exponent of 2.15 and a tortuosity factor of 0.62. Using this formula, the apparent porosity of sediment collocated with core CI-VC-B4 was calculated to be 68.8 percent, consistent with the bulk porosity of the core which was 69% (Braje et al. 2021).

Unfortunately, due to strong currents between the islands, the CUESI profile could not be collocated with the acoustic reflection profile shown in Figure 34. However, the mound associated with core CI-VC-B4 is the intersection point of the two profiles (the CUESI profile has a 112 degree heading and the acoustic reflection profile has a 52 degree heading) and is apparent in both profiles. The mound in Figure 34 appears to be a 45 meter-wide discrete feature within marine sands. In the top panel of Figure 33, a 45 to 50 meter-wide discrete high-conductivity feature is observed to be collocated with the mound, showing good agreement between acoustic reflection data and the apparent resistivity profile.

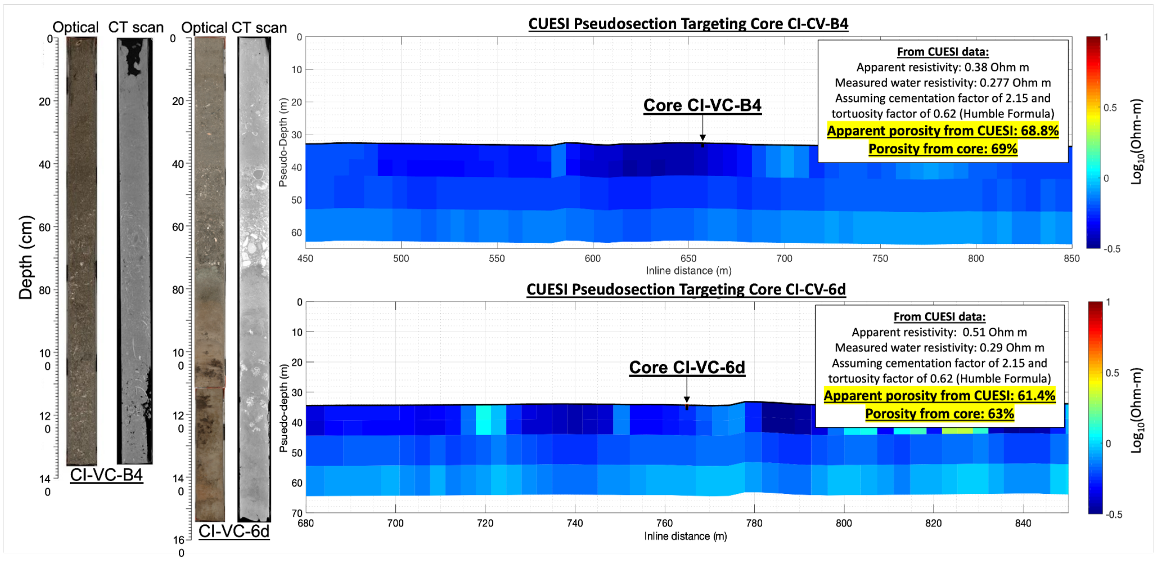


Figure 33: The top profile is a pseudosection generated from a CUESI survey targeting core CI-VC-B4. The CI-VC-B4 core is from a mound-like feature within marine sediment as shown in Figure 34. The bottom profile is a pseudosection generated from a CUESI survey targeting core CI-VC-6d. The CI-VC-6d core contains lithics and layers of silt resulting in a lower overall porosity value compared to the surrounding sediment. Photos and CT scans of both cores are shown to the left.

The bottom panel of Figure 33 is a pseudosection created from data collected while targeting core CI-VC-6d. This core is predominantly composed of sand, fragmented shells, lithics, and thin layers of silt resulting in moderately porous sediment. Again, using the Humble formula, the apparent porosity of the seafloor collocated with the core was calculated to be 61.4% whereas the bulk porosity of the core was 63% (Braje et al. 2021).

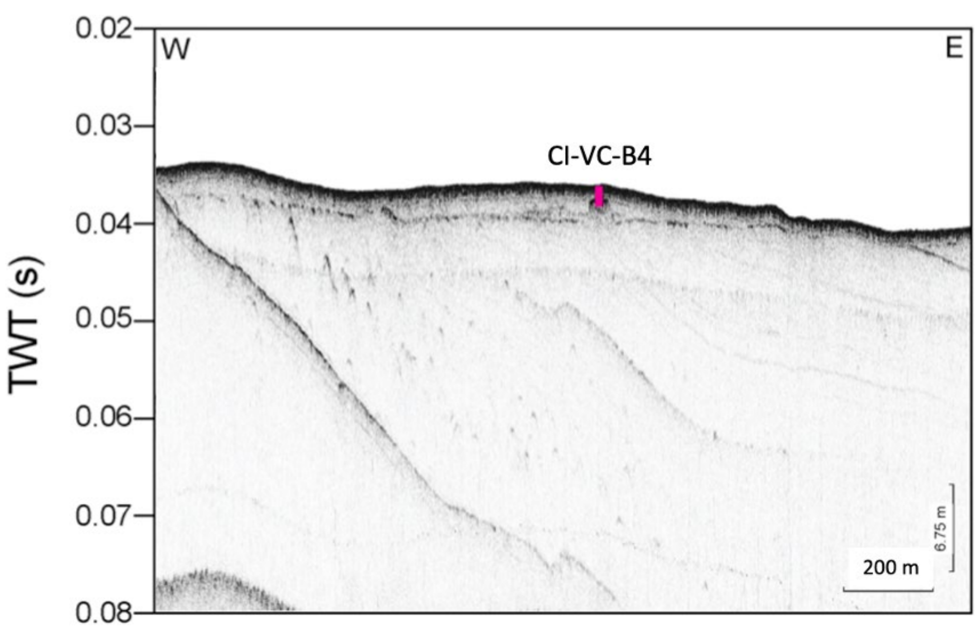


Figure 34: High-resolution Chirp subbottom profile over core CI-VC-B4 collected in 2016.

The agreement between apparent porosity values from the CUESI system and the core porosity indicates that the CUESI system is sensitive to the porosity of the shallow subseafloor. However, this test was extremely limited and the CUESI system will need to be tested over more core locations and over a variety of seafloor types before determining the overall sensitivity of the system.

Comparison with existing CSEM systems – Channel Islands National Marine Sanctuary
The final case study compares the most current version of the CUESI system with existing CSEM systems at the Channel Islands National Marine Sancutary. The CUESI system provided higher-quality data and increased navigational constraints, enabling direct comparison with the resistivity profiles generated by the surface-towed CSEM system.

The CUESI system re-surveyed a previously mapped profile covered by the surface-towed CSEM system, Porpoise, revealing higher-resolution subseafloor resistivity. Using a 25 Hz 2.8 Amp square wave on a 2-meter horizontal dipole, the CUESI system captured data over approximately 2350 meters of seafloor. This data was processed as described by Meyer et al. (2011) and the phase data from the second towfish and amplitude and phase data from the third towfish were included in an inversion.

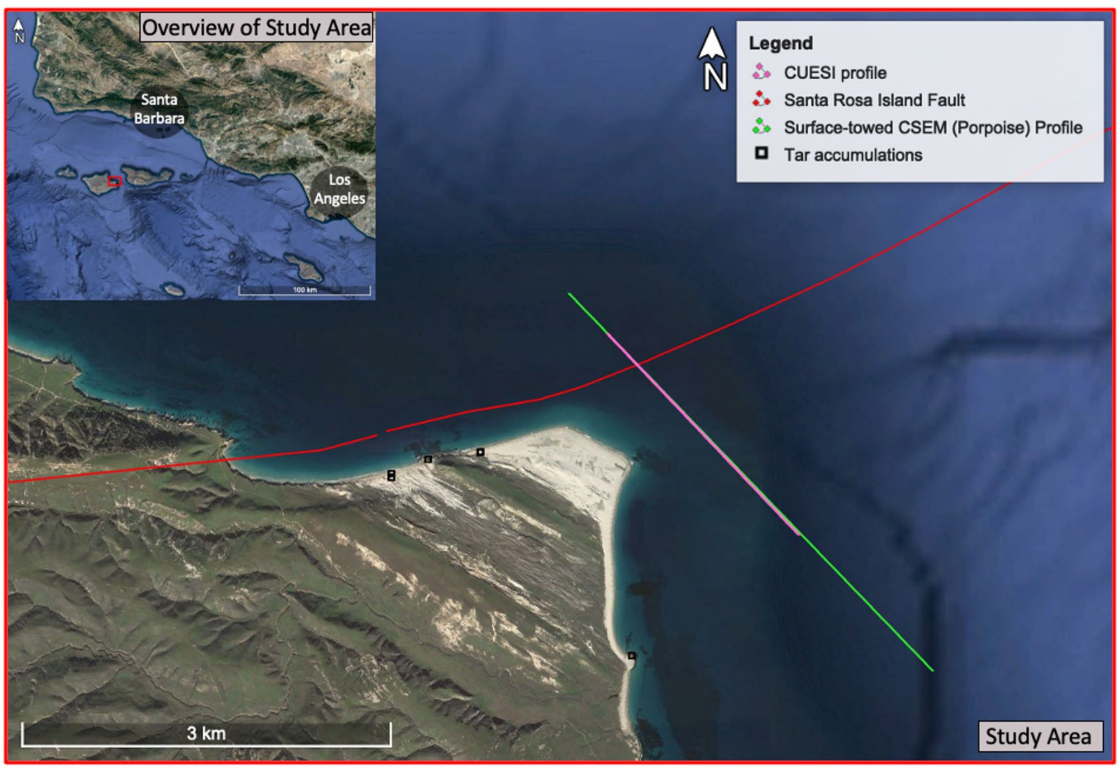


Figure 35: Location of the resistivity profiles presented in Figure 36. The green line marks the location of the surface-towed CSEM survey and the pink line marks the location of the CUESI survey line. The red lines represent the surface trace of the Santa Rosa Island Fault which crosses through both surveys and is marked with a dashed red line in Figure 36. Black squares mark the locations of documented tar accumulations on the beaches from Lorenson et al. (2009).

Employing the MARE2DEM inversion code, the resistivity inversion was run until the final model response converged to a root-mean-square misfit of 1. The resulting 'CUESI Profile' was compared with the 'Porpoise Profile' from the surface-towed CSEM data, demonstrating agreement in co-located areas (see Figure 32). The CUESI system offered enhanced resolution due to shorter source-receiver offsets and higher source frequencies, revealing significant differences in sensitivity depth compared to the Porpoise system. While the Porpoise system displayed sensitivity to depths around 400 meters below sea level, the CUESI system showed a depth of sensitivity between 60 to 90 meters below the seafloor.

The higher resolution of the CUESI model was evident in the clearer fault trace of the Santa Rosa Island Fault, demonstrating a more defined resistive structure compared to the smoothed Porpoise profile. The CUESI system also identified potential hydrocarbon seeps at the seafloor, corroborated by photos captured during the survey and resistivity profiles. These observations suggested the presence of tar accumulations and previously unidentified hydrocarbon seeps associated with the Santa Rosa Island Fault.

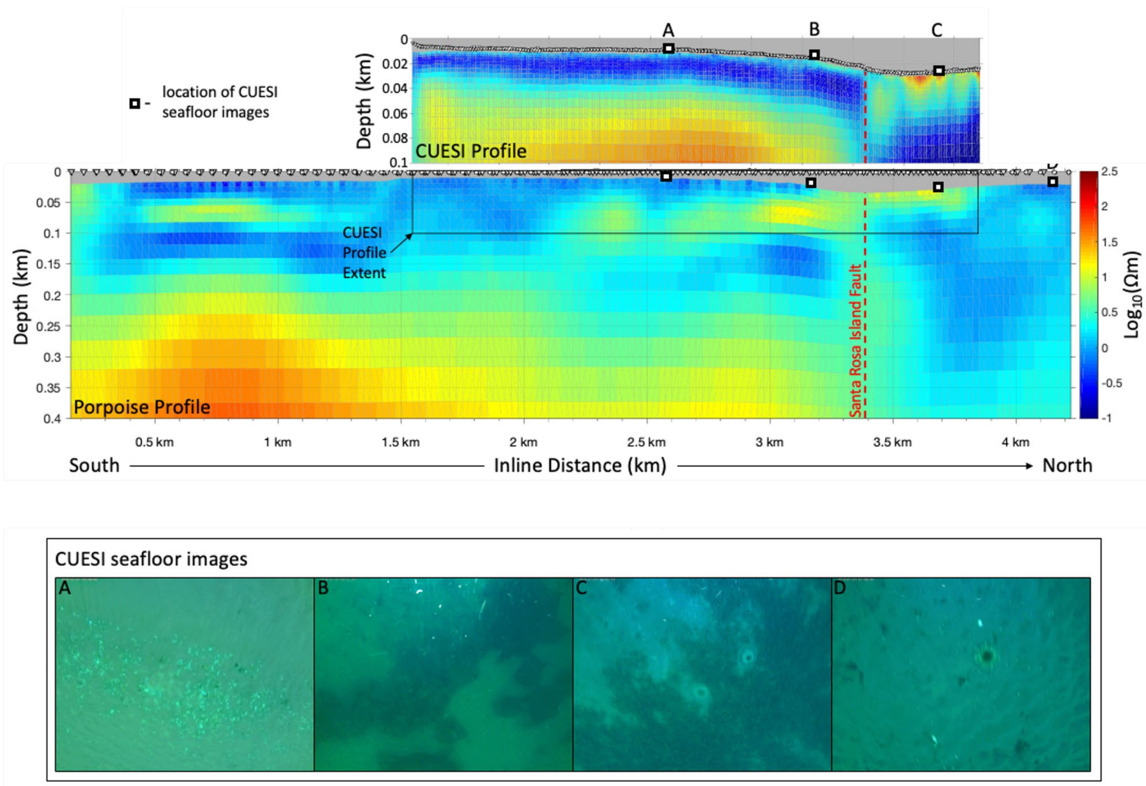


Figure 36: Resistivity models from the CUESI survey and surface-towed CSEM (Porpoise) survey offshore Santa Rosa Island. The top panel, labeled ‘CUESI Profile’, is a resistivity model from the survey line mapped as a pink line in Figure 35. The location of the CUESI profile is marked by a black box on the middle panel. The middle panel, labeled ‘Porpoise Profile’, is a resistivity model from the surface-towed CSEM survey mapped as a green line in Figure 35. Warm colors indicate high resistivity and cool colors indicate conductors in both resistivity profiles. The black and white circles and triangles in both profiles mark the locations of the transmitters and receivers used in the modeling code. The black squares on both the top and middle panels are the locations of the photos captured by the CUESI system and shown in the bottom panel.

II.4.a.iii. Use of Subbottom and CSEM as complementary methods

Typical surveys for archaeological deposits on submerged landscapes use a combination of side scan and subbottom remote sensing methods. These produce hundreds of images of anomalies on and beneath the sea floor. Choosing which of these may be an archaeological deposit relies mainly on size of anomaly and landscape context. By incorporating CSEM survey, the output is sensitive to physical properties independent of those detected by acoustic methods. This reduces the non-uniqueness of the anomalies and provides a separate data set to consider for more targeted sampling of identified features. Identification of these features would benefit from an approach that considers not only the context in which the site is located, but also the physical properties of the site itself. CSEM methods can provide this latter aspect to finding features, and can provide more data on the geology and development of the landscape itself, making the results useful to a variety of disciplines.

During this process, we also identified a number of subbottom water column signals that were consistently identified in our survey areas. These are observed as anomalous noise in the water above the seafloor. Noise in the water column could be caused by numerous sources including marine animals, seaweed growing up off the seafloor (kelp is common in our study areas), fluids and gasses emitted from the seafloor, or resonance noise generated from submerged lithic artifacts. Most relevant to this study would be the identification of noise caused by fluid emission, which may be related to tar seeps, and resonance noise which may be related to preserved archaeological sites. A new method, known as the Human-Altered Lithic Detection (HALD) method has been successfully used to detect Stone Age archaeological sites in shallow marine environments using water column signals in subbottom data (Grøn et al. 2021). The theory of this method is that human-altered lithic artifacts generate an acoustic resonance response when they are struck by a Chirp pulse, and this signal is then detected in the water column above the location of the artifacts. Based on laboratory and field data, it is generally hypothesized that human-altered lithics generate a unique response that should be identifiable from other water column noise, and that naturally broken rocks do not generate the same response. However, very few field studies have been conducted to test the method.

To refine the cause of observed water column signals in the Chirp data we collected, we grouped the observed water column signals into five categories based on their acoustic character. These are described below and presented in Figures 37-40 with their collated CSEM data.

1. *Waterfall signal* - The waterfall signal is chaotic and extends above wide swaths of the seafloor. It has a vertical linear striping appearance between darker and lighter signals. The signal extends upward through the entire water column (Figure 37).
2. *Haystack signal* - The haystack signal is observed as discrete columns, or stacks, of parabolic reflectors. Many columns extend upward through all of the visible water column, but some are only present just above the seafloor (Figure 38).
3. *Stringy signal* - The stringy signal has a stringy appearance that often is observed in bunches. The signal does not extend through the entire water column (Figure 39).
4. *Discrete signal* - The discrete signal is observed as discrete columns of dark, chaotic, signal with no real structure within the column, mostly extending through the entire visible water column (Figure 40).
5. *Blotchy signal* - Similar to discrete signal with columns of dark, chaotic, signal, but signal does not extend through the entire visible water column (Figures 39 & 40).

Next, we compared the Chirp water column noise signal distribution to CSEM resistor distribution to identify patterns that may indicate the presence of tar. A colocated resistor with water column noise, for example, could be generated by a hydrocarbon source that is actively emitting fluid in the water. Alternatively, a water column signal associated with rocky seafloor and non-resistive CSEM signals could instead indicate the presence of kelp or other seaweeds. We then selected ROV targets that would visit a variety of different signal combinations to ground truth the geophysical data observations and elucidate the causes of the Chirp and CSEM signals.

During the current project we used both subbottom and CSEM and collated the data from each instrument to select targets for ROV survey and sampling. This reduced the number of targets that may have been identified using only subbottom or CSEM data independently. Although difficult to quantify, Figure 40 demonstrates the extent of Chirp subbottom signals and CSEM signals that were mapped offshore Anacapa Island. It was clearly not feasible to visit all signals with the ROV, so combining information about where Chirp and CSEM signals overlapped was helpful in determining the likely cause of the signals and deciding which were most crucial to ground truth. During this process, we also identified a number of subbottom water column signals that were consistently identified in our survey areas. These are observed as anomalous noise in the water above the seafloor.

Coal Oil Point

As previously discussed, Coal Oil Point is a region of extensive hydrocarbon production and seepage. In the Chirp data, the water column signal observed within the region of known seep gas distributions from Hornafius et al. (1996) is associated with the waterfall signal (Figure 37). CSEM profile NPT Line 4 is co-located with Chirp profile L36. A prominent resistor (COP_L4W) is observed on the western side of the CSEM profile, in the same location as a Chirp Waterfall signal. Several other resistors are mapped adjacent to waterfall signals. On the east side of Chirp Profile L36, a blotchy signal was also mapped, but this signal is not associated with a CSEM resistor. Only one ROV target was visited in the COP region, but visibility was too poor to characterize the seafloor. Nevertheless, based on the association of the waterfall signal with the known seep area and CSEM resistors, we interpret that this type of signal is generated by gas emission into the water column.

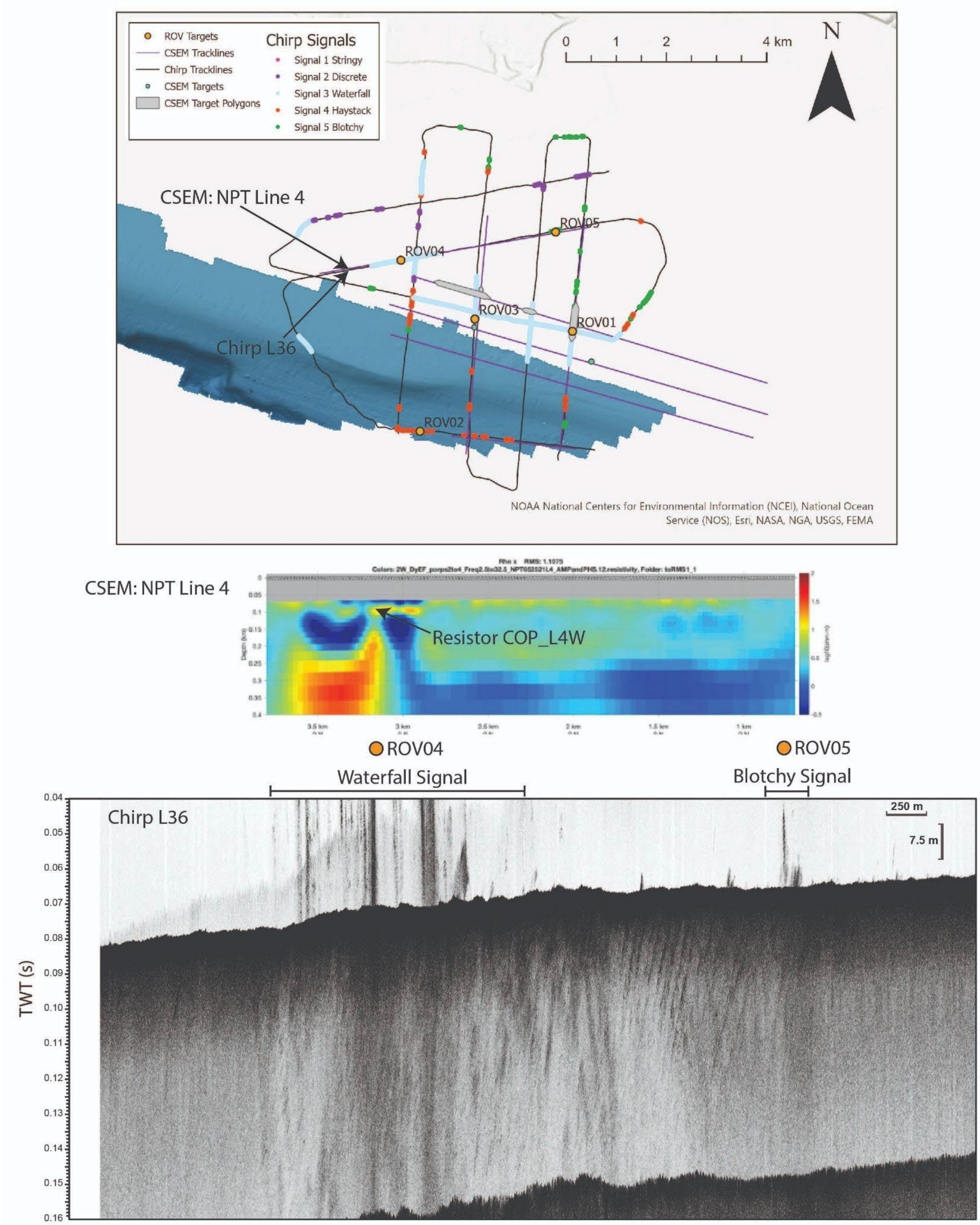


Figure 37: Top: Map of survey location offshore Coal Oil Point. Co-located CSEM (Middle) and Chirp (Bottom) profiles. CSEM profile NPT Line 4 and Chirp profile L36 are located on the same transect (different lengths are shown). NPT Line 4 shows a resistor (COP_L4W) co-located with a waterfall signal in the Chirp data. The Chirp blotchy signal to the east does not align with a resistor in the CSEM profile. ROV targets ROV04 and ROV05 were not visited due to poor seastate and visibility.

Point Conception

Point Conception is another area of known hydrocarbon production and seepage. The Chirp signals in this area were dominated by waterfall and haystack signals. CSEM profile NOAA100321_Line1 is colocated with Chirp profile L44 across the shallowest survey area, which is marked by several seafloor mounds of varying size (Figure 38). Several resistors are observed across this transect and are associated with waterfall and haystack signals in the Chirp data. Therefore, we associate these locations with active seepage into the water column. Both the haystack and waterfall signals may represent gas in the water column, but the distinct haystack signal could also be related to tar seeping into the water. On the CSEM cruise in this region, numerous tar balls were observed floating at the sea surface and the surface towed equipment was covered in tar upon recovery. Unfortunately, the weather conditions prevented any ROV ground truthing of signals in the region. Interestingly a prominent waterfall signal is observed on the eastern side of the L44 profile that does not appear associated with a CSEM resistor. One explanation for this discrepancy is that seeps can be ephemeral. The CSEM and Chirp surveys were conducted ~5 months apart and seep activity may have changed in that time. Alternatively, the seep may be small and within the resolution of the Chirp but outside the resolution of the CSEM.

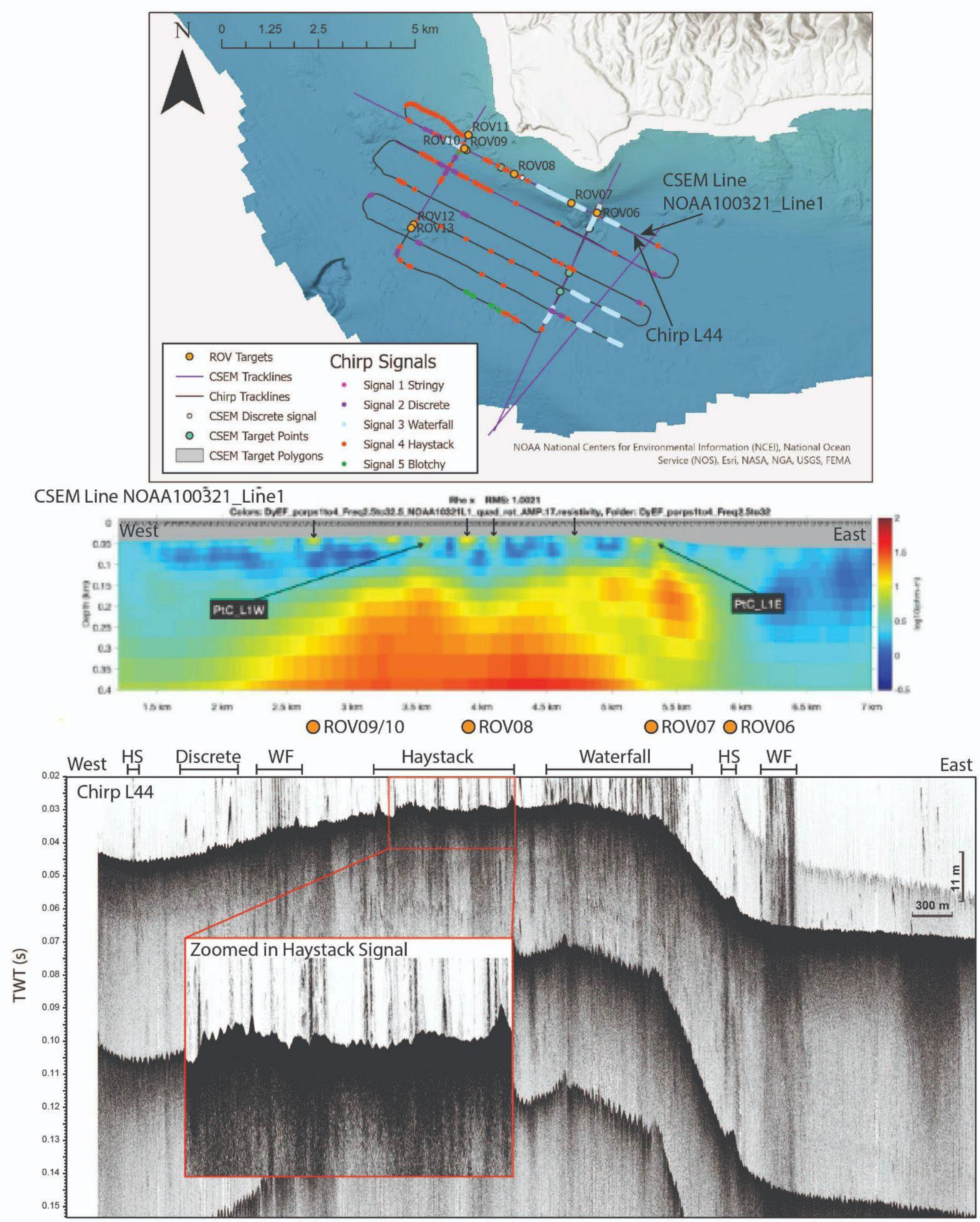


Figure 38: Top: Map of survey location offshore Point Conception. Co-located CSEM (Middle) and Chirp (Bottom) profiles. CSEM profile NOAA100321_Line1 and Chirp profile L44 are located on the same transect (different lengths are shown). NOAA100321_Line1 shows several resistors (PtC_L1W, PtC_L1E, and several discrete resistors marked by black arrows). The Chirp signals across this area are primarily haystack and waterfall signals. None of the ROV targets in the Point Conception area were visited due to poor seastate.

San Miguel Island

The area offshore San Miguel Island is not known for hydrocarbon production but the presence of seeps has previously been indicated. The seafloor of the survey region appears rocky with intermittent smooth areas, likely representing sediment cover. The Chirp signals are dominated by stringy and blotchy signals that are often co-located. CSEM profile NOAA092721_Line1 is colocated with Chirp profile L14 extending southeast-northwest off the northwest side of the island (Figure 39). NOAA092721_Line1 shows two prominent resistors, SMI_L1N and SMI_L1S. In bathymetry data, these are both located on rocky areas. In the Chirp data, SMI_L1N is located near a mounded feature with stringy and blotchy water column signals. The SMI_L1S resistor is located near blotchy water column signals in the Chirp data. The stringy signal character is similar to the structure of seaweed growing off rocky outcrops and its co-location with rocky seafloor suggests it may be related to the presence of seaweed. The blotchy signal is often also collected with rocky seafloor and with the stringy signal, suggesting seaweed as a likely cause. If true, the CSEM signals could be generated by changes in lithology rather than the presence of hydrocarbons. Alternatively, there may be hydrocarbons present, but no seepage into the water column. There is also a slight increase in overall water column background noise at the location of SMI_L1N (Figure 39), which could indicate these areas are seeps but also rocky areas of seaweed growth. None of the ROV targets for CSEM/Chirp data verification were visited due to poor weather and visibility conditions.

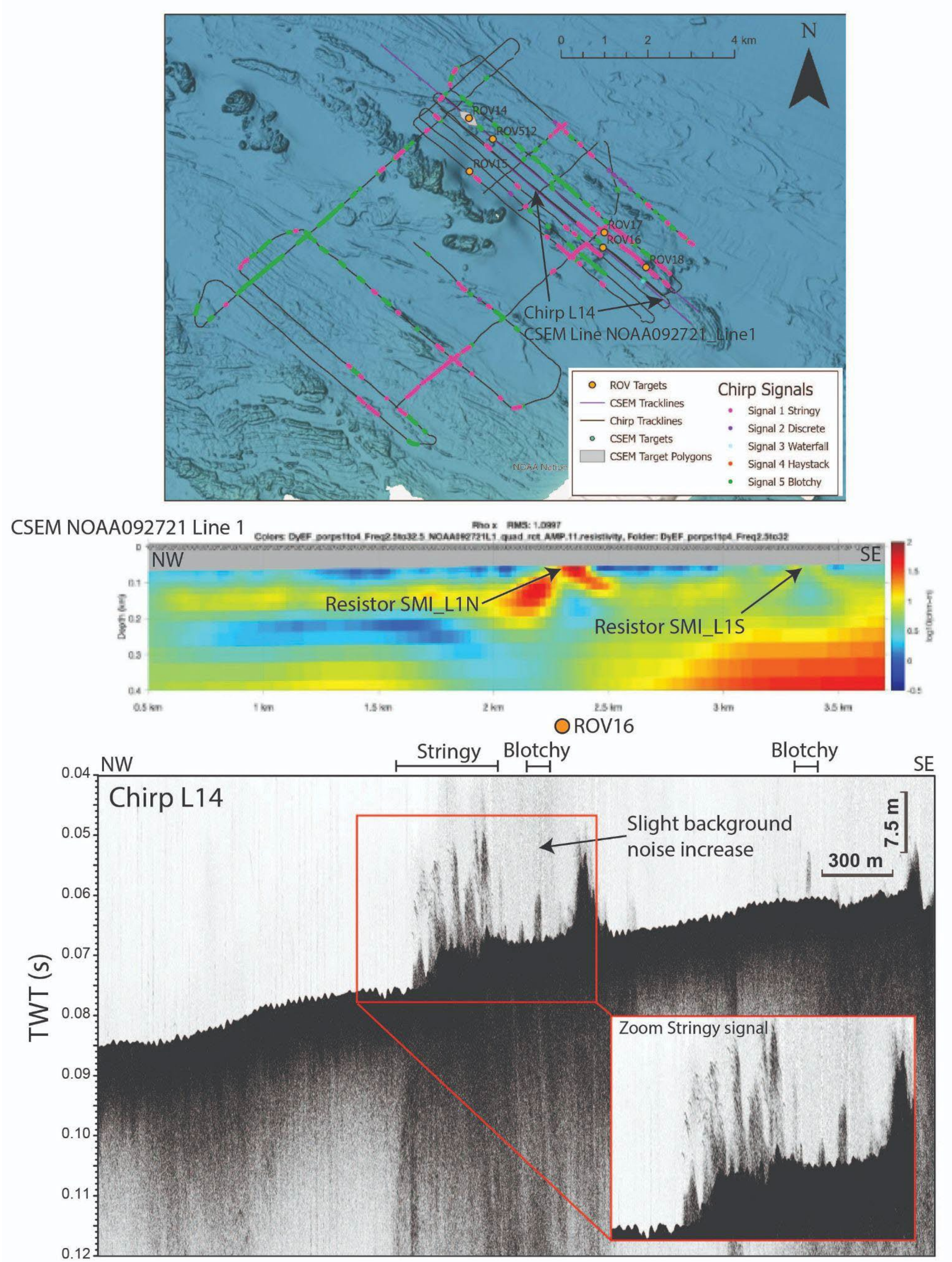


Figure 39: Top: Map of survey location offshore San Miguel Island. Co-located CSEM (Middle) and Chirp (Bottom) profiles. CSEM profile NOAA092721_Line1 and Chirp profile L14 are located on the same transect (different lengths are shown). NOAA092721_Line1 shows two resistors (SMI_L1N and SMI_L1S). The Chirp signals across this area are primarily blotchy and stringy signals. None of the ROV targets in the San Miguel Island area were visited due to poor sea state.

Anacapa Island

The region north of Anacapa Island is not known for hydrocarbon production. The Chirp signals vary over the region with primarily stringy signals closest to the island, blotchy signals farther offshore to the east, and haystack/discrete signals farther offshore to the west (Figure 40). CSEM profile NOAA092921_Line2 is colocated with Chirp profile L27 extending ~north-south off the north side of the island (Figure 40). NOAA092921_Line2 shows three resistors, ANA_L2N, ANA_L2C, and ANA_L2S. Resistor ANA_L2N is adjacent to a patch of discrete/blotchy Chirp signals, ANA_L2C is near discrete/haystack signals, and ANA_L2S is located under discrete signals. Although these signals do not align perfectly, the presence of subbottom resistors and nearby water column noise may suggest emission of gas into the water column from a hydrocarbon source.

Two ROV dives were completed along the same transect as CSEM profile NOAA092921_Line2 and Chirp profile L27. The dive to ROV21 revealed rocky seafloor with sea fans attached to rocky areas, but no evidence of hydrocarbon seeps that would explain the coupled CSEM/Chirp signals. The dive at ROV23 revealed sandy seafloor with urchins, but no clear evidence of the source of coupled CSEM/Chirp signals. However, only ~300 m to the west, ROV24 was visited where seafloor pockmarks were observed in bathymetry. At that location, white beggiatoa mats were observed and sampled, indicating active methane seeping. Based on the CSEM and Chirp data, the source of the discovered active methane seep to the west may extend farther to the east than is observed at the seafloor. The CSEM and Chirp signals closer to the island may reflect more resistive rocks, and potentially hydrocarbons, in the subsurface with rocky exposure at the seafloor allowing sea fan growth that generates a stringy Chirp signal. From ROV dives close to the island, the rocks exposed at the seafloor appeared to be shale or volcanic. The shale could represent Monterey Shale, which is a known hydrocarbon reservoir in the Santa Barbara channel region and could explain the resistive signals.

During the R/V *Sally Ride* cruise, additional subbottom and bathymetry data were collected north of Anacapa Island with new instruments. The SBP29 subbottom system was much better than the previous subbottom surveys at imaging the stratigraphy below the seafloor. However, little water column noise was observed. A comparison of the SBP29 and Edgetech 512i across the same transect is shown in Figure 41. On this transect, an area of subseafloor gas wipeout is observed in SBP29 data below where a large swath of discrete and haystack signals are observed in the 512i data. This could indicate that the instrument characteristics (e.g., frequency range, filtering, beam widths) differ in their ability to image water column noise, or that more gas seepage was occuring during the 512i cruise compared to the SBP29 cruise. The SBP29 system overall did not image much water column noise, but it did detect large discrete water column signals near the large pockmark associated with the discovered methane seep.

Overall, the resistors and stringy/blotchy Chirp signals near the island are interpreted as rocky areas with seaweed and sea fan growth. The resistors near the seep location are more likely related to hydrocarbons in the subsurface and the more prominent haystack and discrete water column signals are more likely related to gas emission from the seafloor.

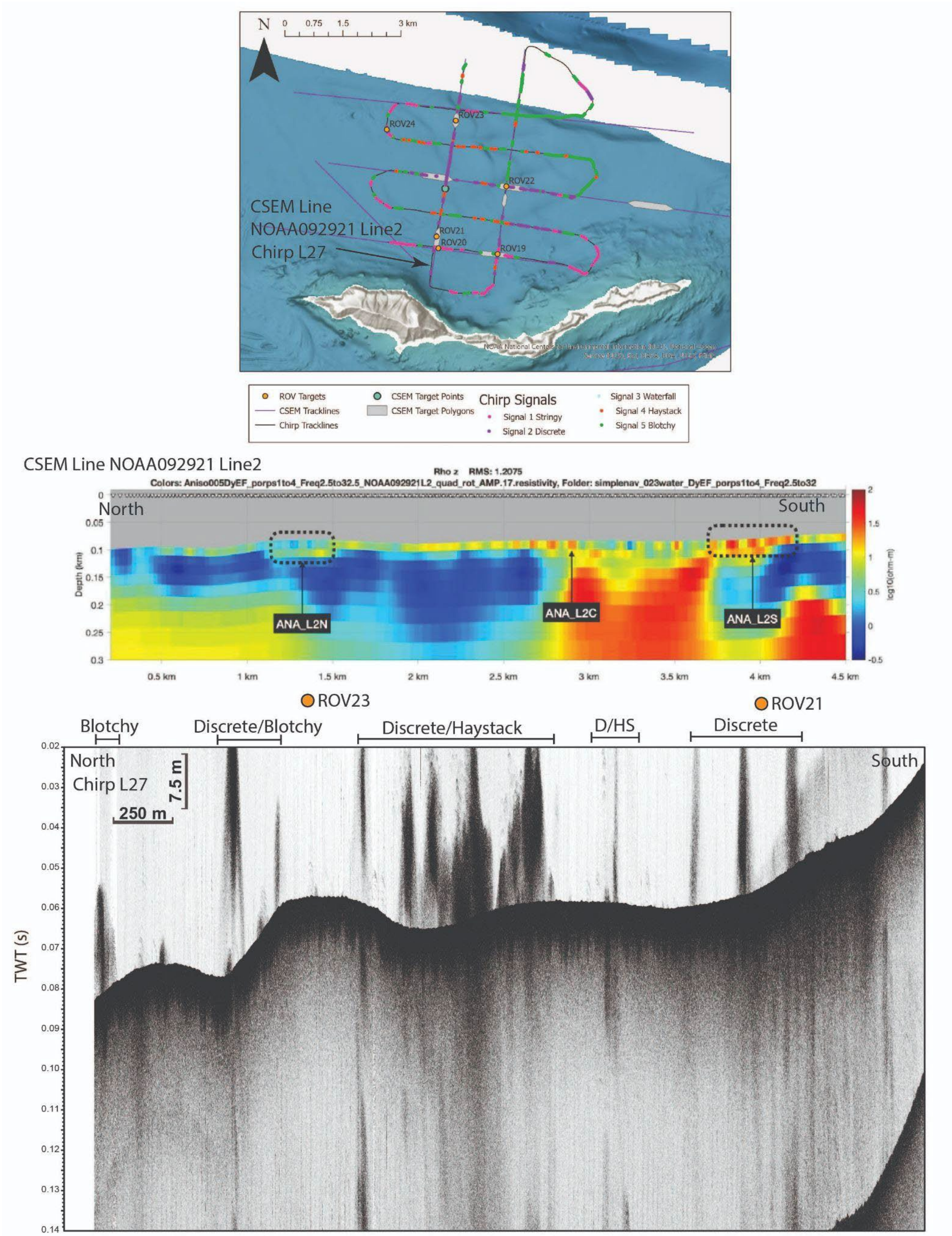


Figure 40: Top: Map of survey location offshore Anacapa Island. Co-located CSEM (Middle) and Chirp (Bottom) profiles. CSEM profile NOAA092921_Line2 and Chirp profile L27 are located on the same transect (different lengths are shown). NOAA092921_Line2 shows three resistors (ANA_L2N, ANA_L2C, and ANA_L2S). The Chirp signals vary over the region with primarily stringy signal closest to the island, blotchy signal farther offshore to the east, and haystack/discrete signals farther offshore to the west. All of the ROV targets in the Anacapa Island area were visited.

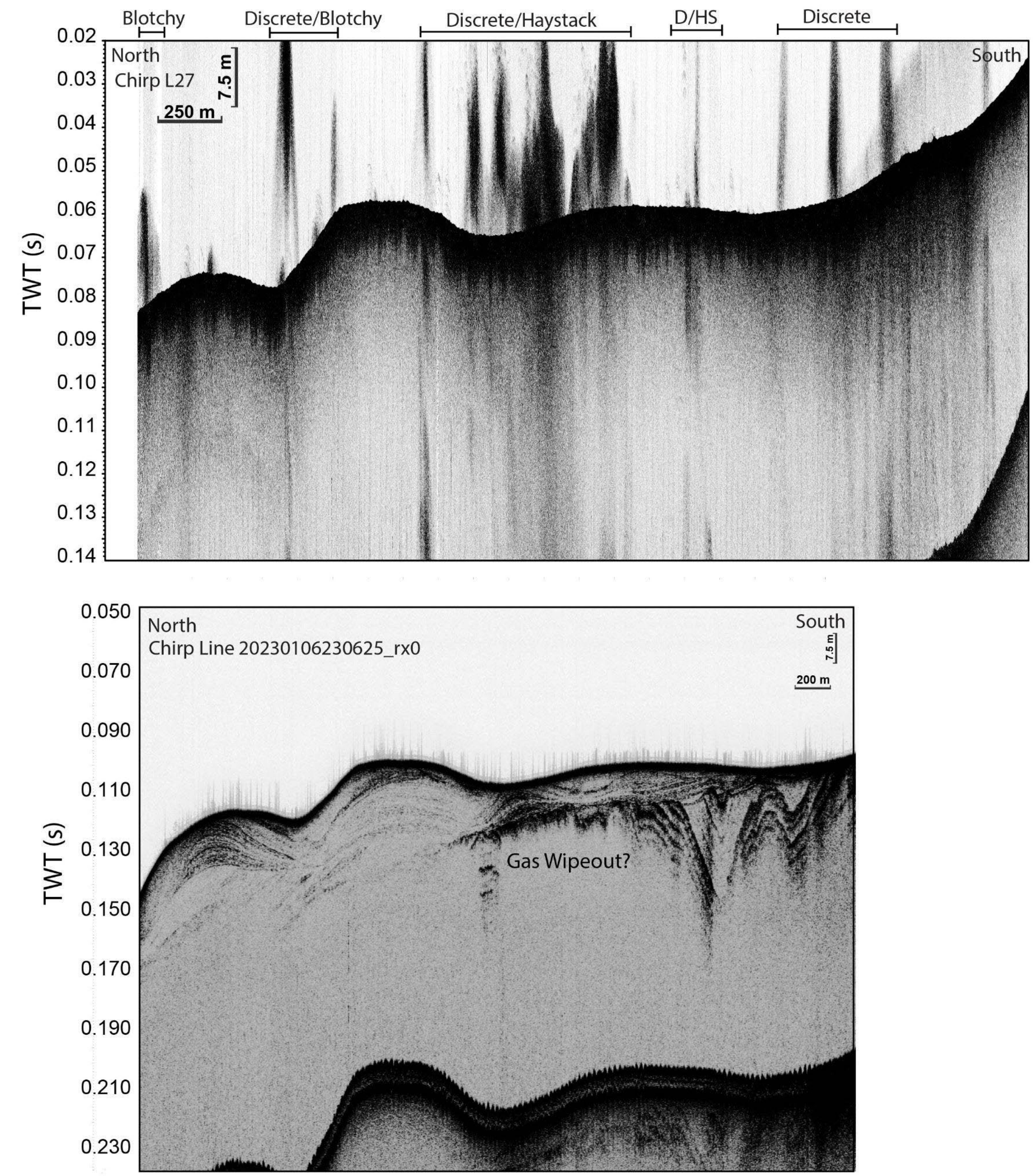


Figure 41: Comparison of Chirp from Edgetech 512i (R/V Shearwater cruise; top) and SBP29 (R/V *Sally Ride* Cruise; bottom). The 512i data shows numerous water column noise signals but little data below the seafloor, while the SBP29 data shows little water column noise but clear stratigraphy below the seafloor.

II.4.a.iv. ***Identification of Cold Seep (Ma saputiwaxmu')***

This research identified the first known shallow water (<100m) cold seep in southern California. This seep has been given the S^{h}amala (Chumashan language) name *Ma saputiwaxmu'* (the place where it seeps through) by the Cultural Department at the Santa Ynez Band of Chumash Indians. This tribe is one band of the Chumash people, the original caretakers of the land where this research was conducted.

Hydrocarbons are inherently more electrically resistive than marine sediment (Constable 2010) and rising fluids and gasses, such as those associated with hydrocarbon seeps, result in anomalous acoustic signatures, as alluded to in the previous section. This means acoustic and EM methods are effective at identifying hydrocarbon seepage at the seafloor, but the type of hydrocarbon seep may still be unknown. In the area north of Anacapa Island, several resistive anomalies that resembled resistive fluid flow below and to the seafloor and anomalous acoustic signatures informally known as 'haystack' signatures were inferred to be related to seafloor seepage (Figure 42). Compared to other regions around the northern Channel Islands, Point Conception, and Coal Oil Point, this area was determined to have the least probability of active tar seepage from prior surveys related to this study.

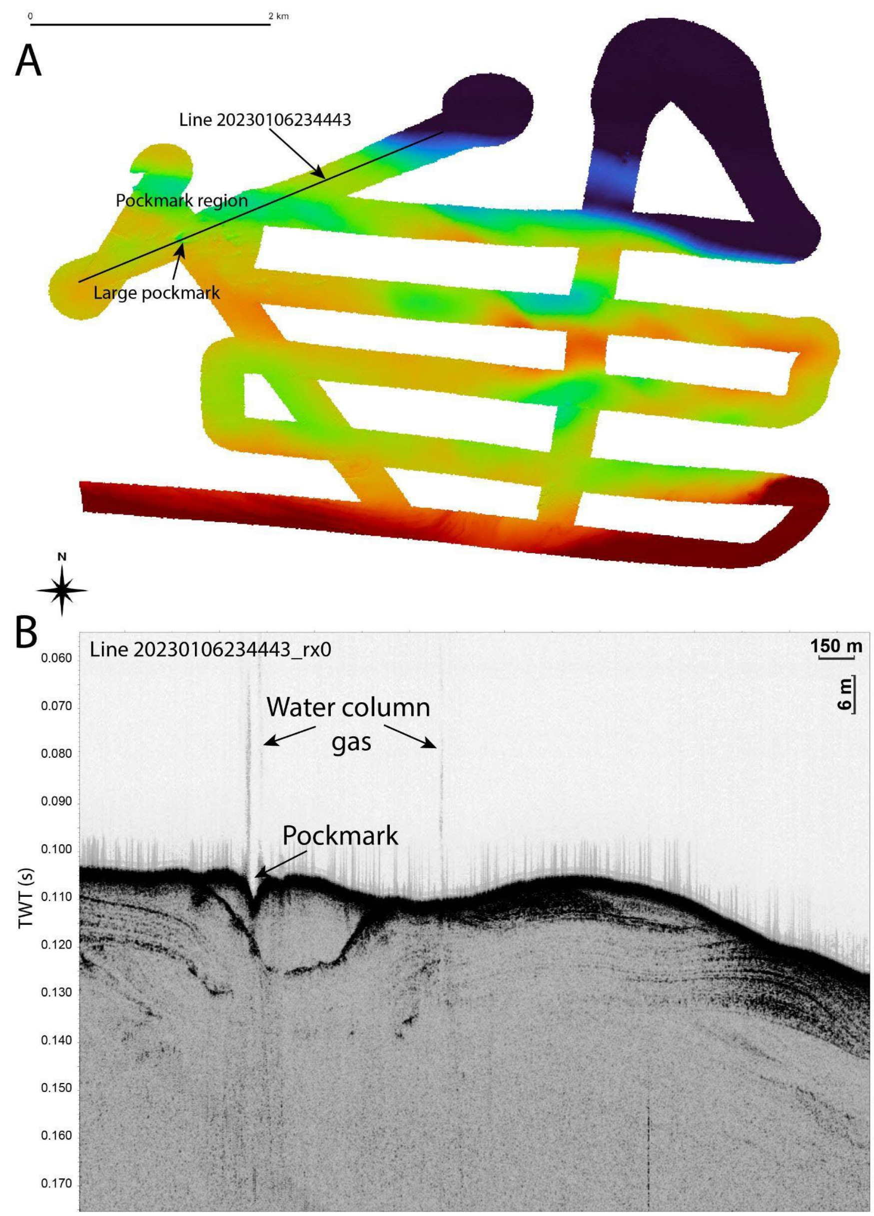


Figure 42: A. New bathymetry collected north of Anacapa Island showing pockmark field at location of methane seep discovered in ROV surveys. B. SBP29 Chirp profile across the largest pockmark associated with the methane seep. Water column noise is observed at the pockmark and to the northeast.

Storm conditions forced the initial 2023 cruise plan to abandon all areas with high probability of active tar seepage and instead focus on the area north of Anacapa Island which still had relatively calm conditions This region has very limited available data outside of this study and so the seafloor substrate, fault trace locations, and general geology of the area are not well constrained. Because of the lack of baseline data, the initial ROV surveys focused on constraining the CSEM and acoustic signatures previously identified in the area. Many of the resistive anomalies, noted to be likely lithologic in origin in early analysis, near the island were identified to be opalized material, likely from the Monterey Formation (discussed below) and unidentified dark, possibly volcanic or metamorphic, rocks consistent with the CSEM signals. Anacapa Island is located on the south-eastern edge of the hydrocarbon-bearing Santa Barbara basin and, here, the source rock of the hydrocarbons is the Monterey Formation. This formation outcrops on the north edge of the basin such as in Coal Oil Point and Point Conception, two of the most prolific hydrocarbon seep fields in the world (Hornafius et al. 1999), but also outcrops to the south on nearby Santa Cruz and San Miguel Islands (Tweet et al. 2020). On Santa Cruz Island, the Monterey Formation is accompanied by volcanics, located on northern side of the Santa Cruz Island Fault, and is made up of predominantly shale and siliceous shale beds (Dibblee 2001).

Notably, during the ROV dive 7 within 1.5 kilometers of the island, the opalized material was interspersed with what appeared to be authigenic carbonate. Most authigenic carbonate forms in the sulfate-methane transition zone (Mozley and Burns 1993), an area below the sediment surface where sulfate and methane, either biogenic or thermogenic in origin, coexist. However, during these ROV dives, no obvious signs of ongoing or active seepage were observed so, if the authigenic carbonates are indeed from a methane seep, the seep is most likely no longer active. It could therefore be inferred that the carbonates identified in ROV dive 7 may be from historic methane seepage from the Monterey Formation, but geochemical analysis and further study of these samples and the ROV footage is necessary to confirm this hypothesis. Authigenic carbonates are thought to represent the only vestige of old gaseous seepage/emissions from the seabed so isotope analysis of these samples will be useful in reconstructing emission rates in the area and their role in the carbon dioxide cycle.

During the ROV dives 3 and 8 approximately 3-3.5 kilometers north of Anacapa Island, we recorded large (>10 meters across) white bacterial mats in two bathymetric lows interspersed with outcropping carbonate reefs (see Figure 43). Bacterial mats are not necessarily indicative of methane seepage; however, the mats were within pockmarks on the seafloor, were collocated with authigenic carbonates and dark sulfur-smelling sediment, and the carbonates, when disturbed, released modest amounts of visible gas bubbles (see Figure 44). Additionally, the subbottom profiles collected across the pockmark area showed tall columns of noise within the water column (see Figure 42). These observations are consistent with those found at active methane seeps, otherwise known as cold seeps. Cold seeps can be found at full ocean depths and are often associated with rich and specialized microbial and benthic faunal populations that take advantage of the seeps' supply of energy-dense gasses and fluids (Jessen et al. 2011; Levin et al. 2016). Here, chemotrophs, or methanotrophs, anaerobically oxidize methane creating bicarbonate (Elvert et al. 1999; Hinrichs et al. 1999; Thiel et al. 1999). This increases the pore water alkalinity causing precipitation of authigenic carbonate minerals (i.e. carbonate reefs) in the shallow subsurface and the release of carbon dioxide (Baker and Burns 1985). The carbonate features can provide anchor points to other forms of biodiversity on the seafloor making previously uninhabitable regions biologically productive (Al-Zaidan et al. 2006; Van Dover and Fry 1994). Most famously, in the deep ocean, below the photic zone, cold seeps can support prolific ecosystems despite the lack of light due to the presence of chemotrophs (Tunnicliffe et al. 2003). The chemotrophs provide energy (organic carbon) through chemosynthesis in lieu of photosynthesis for local fauna, but also habitat through deep-sea reefs. These deep-sea ecosystems can represent discrete areas of dense biodiversity, such as tubeworms, mussels, and soft corals, in an area of otherwise low biological activity (Dando 2010). To date, the majority of research on cold seeps and the related fauna has been focused on seeps located in dark or low-oxygen waters, but little is known of the seep characteristics and the bacterial communities in shallow, oxygen-rich continental shelf environments (Paul et al. 2017; Ruff et al. 2015) such as the seeps encountered during this ROV survey.

At shallow water depths, such as on continental shelves where light penetrates to the seafloor, chemotrophs must compete with fauna that rely on photosynthetic carbon. Thus, cold seeps in shallow depths must be more productive than the seeps found in the deep ocean for the same abundance of chemotrophs to persist (Ding and Valentine 2008; Montagna et al. 1987). Therefore, in the ROV dives offshore Anacapa Island, the presence of large bacterial mats indicate that methane is actively being released into the marine environment, a fact supported by the presence of water column noise in the Chirp data. Bacterial mats are a major sink of methane transport into the atmosphere (Paul et al. 2017) so the lack of visible gas bubbles could indicate that most of the methane rising from the sub-seabed is being used by anaerobic oxidation close to the seabed by the mats (Boetius and Wenzhöfer 2013). The diversity of carbonate structures ranging from low to high relief structures combined with the higher rates of sedimentation on continental shelves could indicate that these cold seeps have been active for centuries or longer (Levin et al. 2016).

Several studies have found that persistent and established cold seeps are often associated with tubeworm aggregations within 1.1 kilometers of the seep (Bowden et al. 2013). Although live tubeworms were not observed during this survey, an abundance of abandoned Vermetidae tubes were found within 1 kilometer of the bacterial mats associated with carbonates, in a bathymetric low during ROV dives 12 and 13. Also, during these dives, several large (>3 meters across) bacterial mats were observed (see Figure 43); however, no carbonates were identified near the mats. This area had more dark staining (interpreted to be black sulfuric sediments) compared to other areas with bacterial mats. This indicates that the cold seep may be younger than the other seeps identified or that another type of bacteria (e.x. sulfur oxidizing bacteria) may be prevalent. Here, for comparison with the other mats encountered in prior dives, four sediment samples were collected to help identify the mats in this region. Live bacteria can be seen in Figure 46 in the form of fine white hairs within the dark sediment. This sediment will be prepared for geochemical and microbial analysis.

Evidence for past and current cold seep activity with a variety of characteristics was noted during the ROV dives offshore Anacapa Island and the data and samples collected could provide useful information when reconstructing both the paleoenvironment and paleoclimate of the region. Cold seeps provide habitat for specialized pelagic and benthic communities which have influence on the marine environment far beyond the footprint of the seep itself. This is because seeps and their sites are both major sources and sinks of global carbon, making these areas key players in global biogeochemical budgets (Levin et al. 2016). Recent estimates show that cold seep flux may account for up to 35% of the world's methane total emissions; but, incredibly, these sites only contribute 1% to 5% of the net methane emissions in the atmosphere due to the bacterial activity, or biological filter, at the seeps sites (Dickens 2003; Kvenvolden and Rogers 2005; Milkov et al. 2003). However, these estimates are predominately derived from global-scale modeling and from site studies in deep-water environments which may not be representative of seep and mat behavior at shallower depths. The sites identified in this study are in shallow water (<100 meter water depth) and the geochemical and microbial analysis of the samples may constrain the activity and metabolic rates of the mats currently present at the seeps. Additionally, offshore Anacapa, the cold seeps provide hard substrate in an area of otherwise predominately soft substrate. From the ROV footage, it appears both chemotrophs and phototrophs (e.x. corals) have taken advantage of the habitat giving rise to areas with higher biological activity than the surrounding area. As stated above, this is not unusual, and bacterial mats can become keystone species for the local natural environment (Levin et al. 2022). These ecosystems are understudied and recent analysis indicates that many shallow cold seeps are already being impacted by human activity leaving the local ecosystems vulnerable (Noble-James et al. 2020). Although outside the scope of this study, the seeps identified offshore Anacapa Island could be used to better the understanding of the communities reliant on the seep activity and thereby minimize the disturbance from human activity. The location of the seeps is easily accessible by a number of research institutions (several of which are already actively involved in cold seep studies elsewhere) in Southern California, thereby providing an excellent opportunity for further study of the ecology of cold seeps on continental shelves.

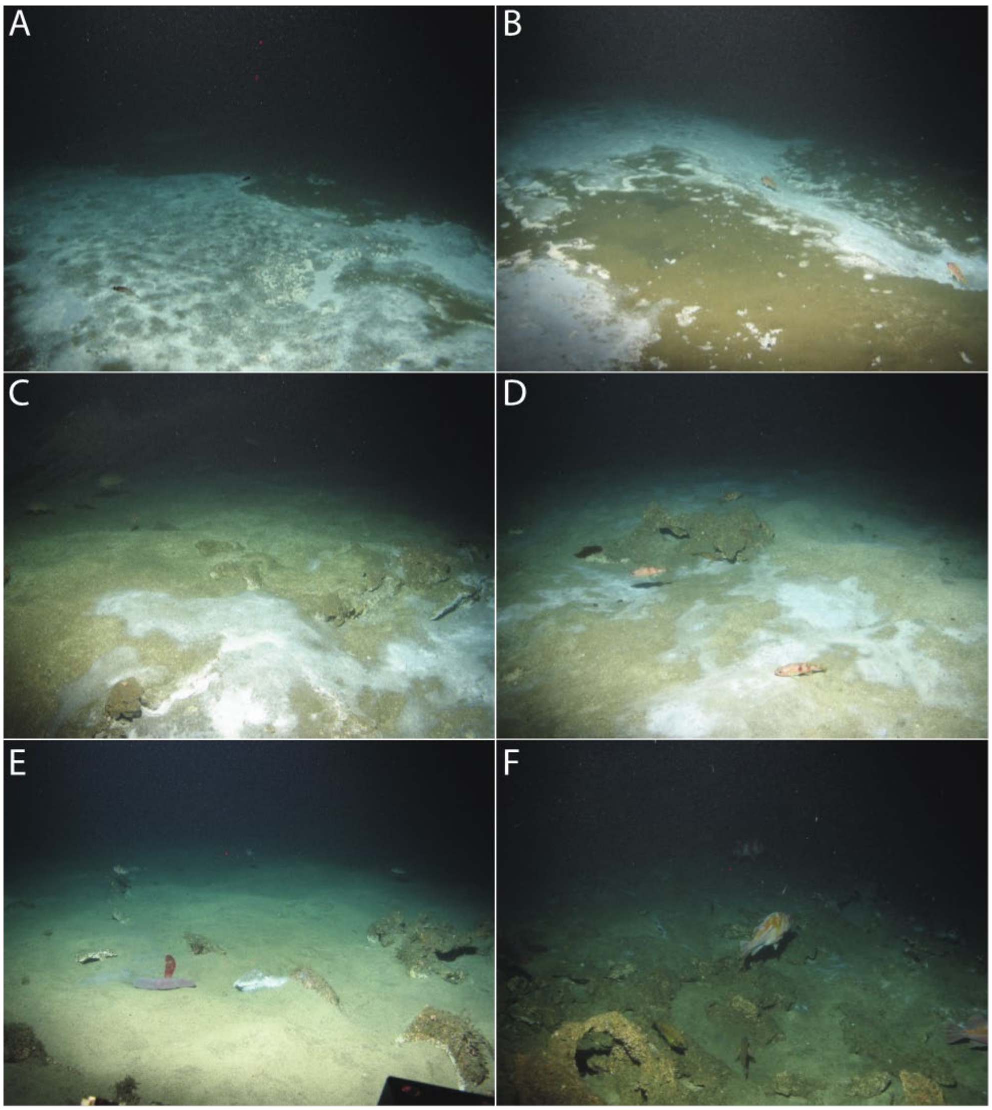


Figure 43: Photos of various bacterial mats encountered during ROV dives 3 to 3.5 kilometers north of Anacapa Island. Images A and B are areas with thick (several centimeters) bacterial coverage, some dark seafloor staining (interpreted to be sulfate staining), and minimal/early carbonate development. Figures C and D are areas with 1- to 2-meter-wide bacterial mats with low to moderate relief carbonates. Active carbonate formation is shown in Figure E. Figure F has abundant moderate to high relief carbonates that are representative of typical authigenic carbonates with small (<20 centimeter) patchy bacterial mats.

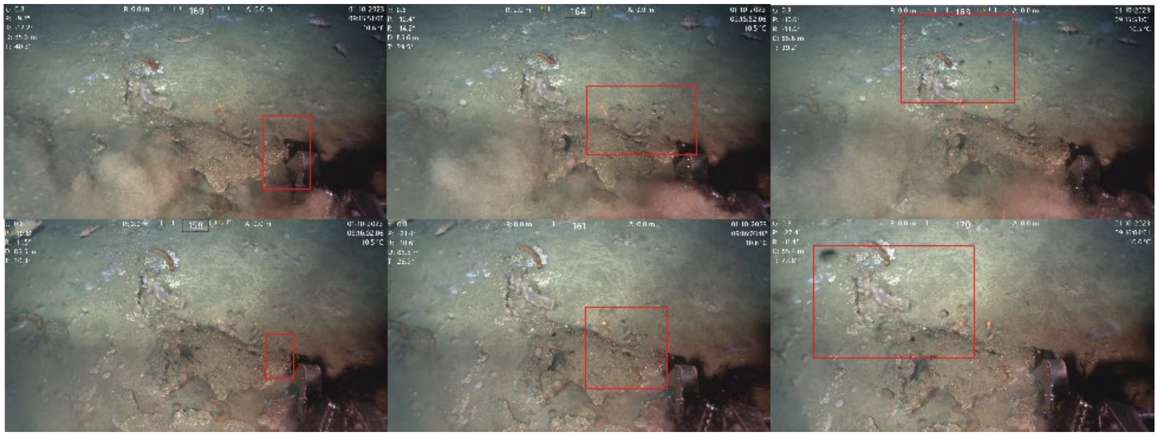


Figure 44: Video forward stills of gas release from seafloor carbonates when disturbed with ROV manipulator arm. The red boxes in each frame indicate the location of bubbles which, due to the resolution and angle of the images, may be difficult to see. Bacterial mats are also captured in these stills.

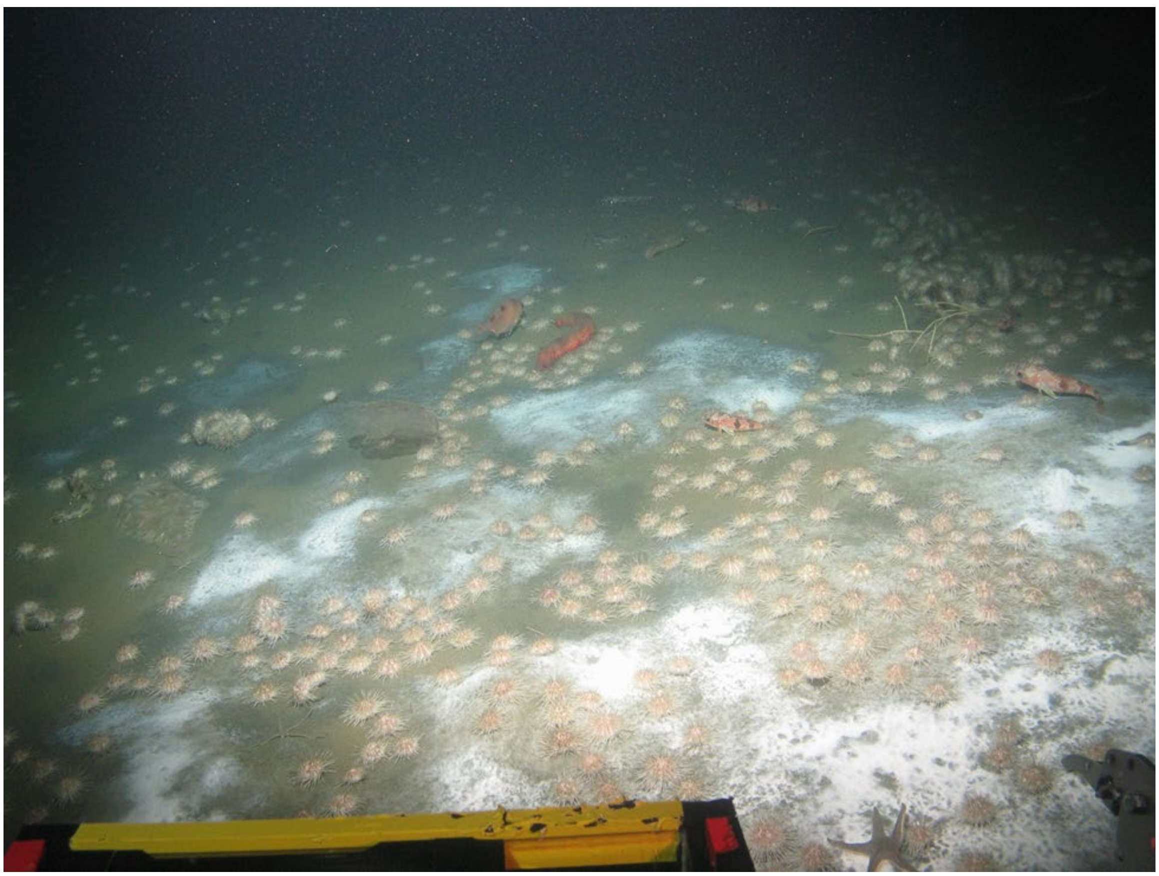


Figure 45: Photo still from ROV dive 12 of white bacterial mats covering dark-colored sediment with abundant sea urchins.

Figure 46: Sediment sample from bacterial mat. The sample smelled strongly of sulfur consistent with the environment these bacteria are known to thrive in, the sulfate-methane transition zone. Fine white hairs in sediment are bacteria.

Sample Analysis Results

Two samples were chosen for analysis: SR2023_Anacapa_Rk1 and SR2023_Anacapa_Rk8. During the ROV dives, there were two predominant rock features types encountered (Figure 47). Low relief carbonate structures dotted throughout the survey area that were likely created by the bacteria that feeds on the hydrocarbon seeps. These were seen in regions both with and without noticeable bacterial mats. Other structures appeared to be rock outcrops and were more abundant in areas distant from the bacterial mats. The non-carbonate samples varied, but many appeared dark in color and were found to have bedding and resemble a slate or shale. We tested one of the non-carbonate samples to determine type of mineral and to understand if it was related to the Monterey Formation that is found on the adjacent mainland and the northern Channel Islands. We tested the assumed carbonate for verification that it was a carbonate and likely created by the bacteria present at the seep location.

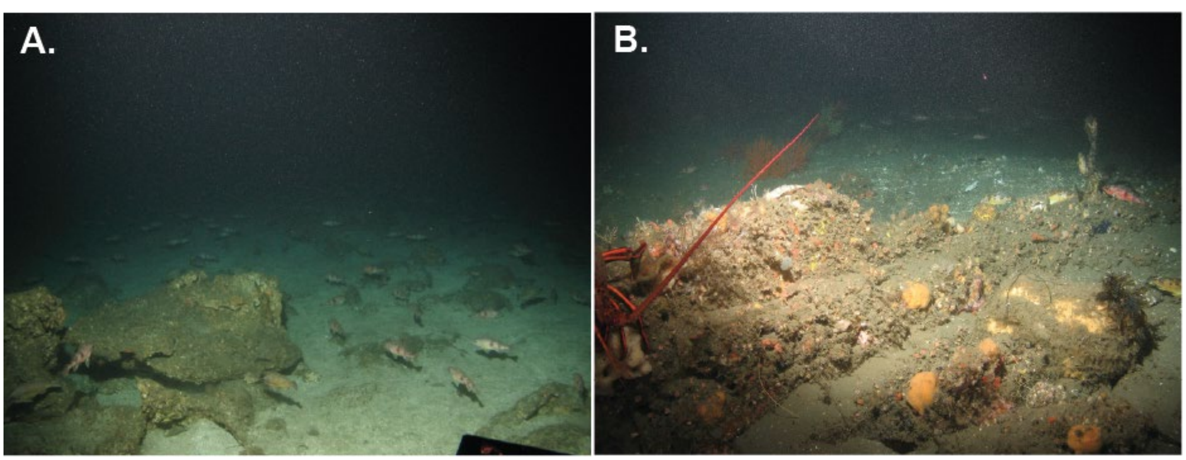


Figure 47: Examples of two types of rock outcrops encountered on ROV surveys. A. Carbonate structures. B. Dark, bedded rock outcrops.

SR2023_Anacapa_Rk1

This sample smelled strongly of sulfur and was dark in color. Analysis shows that SR2023_Anacapa_Rk1 is 90% opal with quartz (< 1%), calcite (~4%) and dolomite (~5%) the major remaining elements. Table 10 shows the chemical analysis with trace Fe and S in the material, as well as definitely reduced Fe2+., possibly explaining the dark color. Previous geochemical testing of the upper siliceous member of the Monterey Formation confirms that this formation can have a high density of opal (Johnson and Grim 2001), though the samples tested with the current research is particularly high in this mineral. The mineral composition indicates that this is diagenetic, due to the presence of Dolomite, and we can assume this is related to the Monterey Formation

Table 10. XRF analysis of SR2023_Anacapa_Rk1

Elem.	Line	Mass [%]	3sigma	Atomic [%]	Intensity [cps/mA]	Formula	Mass [%]	Molecule [%]
11 Na	K	3.63	1.99	4.13	11.31	Na2O	4.89	4.43
12 Mg	K	2.6	0.49	2.8	30.73	MgO	4.31	6
14 Si	K	5.11	0.22	4.75	446.63	SiO2	10.93	10.2
16 S	K	1.18	0.06	0.96	368.92	SO3	2.95	2.07
17 Cl	K	4.27	0.15	3.15	1397.17	Cl	4.27	6.76
19 K	K	0.31	0.03	0.21	116.84	K2O	0.37	0.22
20 Ca	K	48.86	1.45	31.87	19825.97	CaO	68.36	68.41
22 Ti	K	0.45	0.04	0.25	123.74	TiO2	0.76	0.53
26 Fe	K	1.27	0.05	0.59	1104.06	Fe2O3	1.81	0.64
30 Zn	K	0.02	0.01	0.01	29.02	ZnO	0.02	0.01
35 Br	K	0.01	0.01	0	33.99	Br2O	0.01	0
38 Sr	K	1.11	0.04	0.33	3783.91	SrO	1.32	0.71
O		31.18	0.99	50.95	-	-	-	-

SR2023_Anacapa_Rk8

Analysis confirmed that this is a carbonate structure with 65% calcite and 35% aragonite. This mineral combination would be unusual if relying on one species for formation and is likely the result of different lithifying organisms. This may be the product of both organic and inorganic mixing, possibly from nearby sources of upwelling from groundwater precipitating out of the continental shelf. When cut, the sample resembled coquina with many small bits of shell suggesting that the bacterial mats are supporting other lifeforms aside from bacteria. Table 11 shows the XRF chemical analysis. While the XRF did measure silica, there was no crystalline quartz in the XRD data, so this sample could also be opalized.

The results of the analysis suggest that additional analyses would be beneficial to understanding the nature of the cold seep and surrounding environs, as well as the antiquity of the seep field.

Table 11. XRF analysis of SR2023_Anacapa_Rk8

Elem.	Line	Mass [%]	3sigma	Atomic [%]	Intensity [cps/mA]	Formula	Mass [%]	Molecule [%]
12 Mg	K	1.17	0.41	1.01	23.76	MgO	1.93	2.9
14 Si	K	37.21	0.28	27.8	5061	SiO2	79.59	80.02
16 S	K	1.81	0.06	1.18	480.21	SO3	4.52	3.41
17 Cl	K	1.75	0.06	1.04	501.45	Cl	1.75	2.99
19 K	K	0.46	0.03	0.25	175.01	K2O	0.56	0.36
20 Ca	K	5.96	0.09	3.12	3169.43	CaO	8.34	8.98
22 Ti	K	0.13	0.01	0.06	99.85	TiO2	0.21	0.16
23 V	K	0.01	0.01	0	8.77	V2O5	0.01	0
24 Cr	K	0.01	0.01	0.01	21.22	Cr2O3	0.02	0.01
26 Fe	K	2.1	0.03	0.79	5297.88	Fe2O3	3	1.13
30 Zn	K	0.01	0	0	38.75	ZnO	0.01	0.01
35 Br	K	0.01	0	0	39.97	Br2O	0.01	0

Elem.	Line	Mass [%]	3sigma	Atomic [%]	Intensity [cps/mA]	Formula	Mass [%]	Molecule [%]
38 Sr	K	0.04	0	0.01	417.36	SrO	0.05	0.03
40 Zr	K	0	0	0	53.87	ZrO2	0.01	0
O		49.34	0.42	64.73	-	-	-	-

II.4.b. Inventory of activities (number of submersible dives, CTD, net tows, area mapped, technology development milestones, etc.), including maps and/or coordinates

We collected 25 GB of CSEM data over 124.12 km of linear survey, 7 GB of Chirp data over 260 km of linear survey and 3 TB of still and video imagery during 13 dives totaling 36 hours and 48 minutes of bottom time with the ROV. We collected 14 rock/carbonate samples and 4 sediment samples. We have over 400 photos of the crew and boat operations and over 2000 images of the sea floor from a camera affixed to the CUESI system. Project activities and data are in Table 12 and general daily survey activities with instruments and locations are in Table 13. Tables and images with subbottom and CSEM transects and ROV paths can be found in Appendix D.

Table 12. Project activities and data

Activity	Vessel	Collection Dates	Instrument/Equipment	Extent	Data Size
CSEM survey	R/V Bob and Betty Beyster	Sept-Oct 2021	Porpoise & CUESI	124.12 km	25 GB
Chirp subbottom	R/V Sally Ride SR2301	Jan 2023	SBP29	5 km	2 GB
Chirp subbottom	R/V Shearwater	May 2022	Edgetech 512i	255 km	7 GB
ROV Dives	R/V Sally Ride SR2301	Jan 2023	MARE ROV Beagle	13 dives, 36 hours 48 min. bottom time	572 GB
ROV Samples	R/V Sally Ride SR2301	Jan 2023	MARE ROV Beagle	14 rock and 4 sediment samples	NA

Table 13. Project daily cruise logs

Date	Activities
9/20/2021	Mobilization of R/V *Beyster*: Sonar and CSEM towed and top-side equipment, crane operations. Set up sonar top-side equipment, store CSEM tow and top-side equipment. Sonar equipment being used on two-day research cruise in Orange County prior to NOAA cruise
9/25/2021	Transit: Depart Orange County location for Santa Barbara Harbor – Assemble CUESI tow frames after arrival
9/26/2021	Mapping Area SCP: CUESI – CSEM survey fault trace with possible associated seepage offshore eastern Santa Rosa Island and coring locations offshore western Santa Cruz Island
9/27/2021	Mapping Area SMI: Porpoise/Subottom - Co-collect CSEM and Chirp data offshore San Miguel targeting an inferred hydrocarbon seep and characterizing the seafloor
9/28/2021	Mapping area Ventura: Porpoise - Due to weather, operations were shifted away from the Northern Channel Islands and into the calmer area offshore Ventura and Oxnard. The goal of this survey is to detect the extent of the coastal aquifers of these two population centers with CSEM. This region has not been surveyed previously with CSEM methods, but historical records indicate significant freshwater seepage offshore Ventura and Oxnard
9/29/2021	Mapping Area Anacapa: Porpoise - CSEM survey north of Anacapa Island to test for the existence of hydrocarbon seeps.
9/30/2021	Weather day: Use this time to download data, change instrument batteries, and check data quality.
10/1/2021	Area SMI: ROV operations for equipment recovery
10/2/2021	Mapping Area Anacapa: Porpoise - CSEM survey north of Anacapa Island to test for the existence of hydrocarbon seeps.
10/3/2021	Mapping Area Point Conception: Porpoise - CSEM survey a series of previously identified asphalt volcanoes offshore Point Conception as well as survey a region of the seafloor that has pockmarks for possible hydrocarbon seeps using the porpoise system

Date	Activities
10/4/2021	Demobilization/Transit: Demobilize equipment in Santa Barbara Harbor. R/V *Beyster* engaged in another project in area and that team is mobilizing their gear.
5/4/2022	Mobilization R/V *Shearwater*: Santa Barbara Harbor. Sonar and top-side equipment, crane operations. Set up sonar top-side equipment and tested Chirp.
5/7/2022	Transit/Survey SCP: Santa Barbara Harbor to Santa Cruz Passage. Sonar survey. Transit to Bechers Bay for overnight anchor.
5/8/2022	Transit/Survey SMI: Bechers Bay to north San Miguel Island. Sonar survey. Transit to Culyer Harbor for overnight anchor.
5/9/2022	Transit/Survey ANA: Culyer Harbor to north Anacapa Island. Sonar survey. Transit to Santa Barbara Harbor for overnight anchor.
5/10/2022	Transit/Survey COP: Santa Barbara Harbor to La Goleta Tar Seep. Sonar survey. Transit to Cojo Anchorage for overnight anchor.
5/11/2022	Transit/Survey PtC/Demobilization: Cojo Anchorage to La Point Conception. Sonar survey. Transit to Santa Barbara Harbor for demobilization.
1/2/2023	Mobilization R/V *Sally Ride*: Vibracore, ROV, and top-side equipment, crane operations. Unpack crates, secure equipment, and prepare for deck operations. Discuss safety, civility, meal plans, and berthing arrangements onboard.
1/4/2023	Transit: Depart from Marfac at 0800 toward P1: SD (San Dieguito SBP)
	Arrive at Site P1A – sonar and vibracore collection
1/5/2023	Site P1: SD – vibracore
	Transit: Depart from P1: SD (San Dieguito) toward P2: A (Anacapa ROV)
1/6/2023	ROV Survey – North of Anacapa

Date	Activities
1/7/2023	ROV Survey – North of Anacapa & La Goleta Seep Field
1/8/2023	ROV Survey - Area between east of Santa Rosa Island & North of San Miguel
1/9/2023	ROV Survey – North of Anacapa
1/10/2023	ROV Survey – North of Anacapa
1/11/2023	ROV Survey – North of Anacapa
1/12/2023	Demobilization

II.4.c. Inventory of samples collected

We completed a total of 13 ROV dives, gathering 14 rock samples and 4 sediment samples while capturing 33.5 hours of video footage via high-resolution forward and downward-facing cameras. Table 14 shows sample locations and short descriptions. A full inventory with images for the samples is provided in Appendix C.

Table 14. Samples collected during current research

Sample Name	Dive	Date	Latitude	Longitude	Material	Description
SR2301_ Anacapa_ Rk1	1	1/6/2023	-119.4143382	34.02334504	Rock	Slate/shale sample collected near bedded outcrop during first ROV dive north of Anacapa Island. Sample shows bedding and breaks along planes.
SR2301_ Anacapa_ Rk2	3	1/7/2023	-119.4330675	34.04890669	Barnacle	Attempted to sample what appeared to be low relief carbonate on the seafloor on ROV dive 3 north of Anacapa Island. Sample was instead a collection of barnacles.
SR2301_ Anacapa_ Rk3	3	1/7/2023	-119.4329965	34.04893167	Carbonate	Sample collected from what appeared to be low relief carbonate on the seafloor on ROV dive 3 north of Anacapa Island. Sample appears to be carbonate with abundant fauna attached and embedded shells.

Sample Name	Dive	Date	Latitude	Longitude	Material	Description
SR2301_ Anacapa_ Rk 4	7	1/9/2023	-119.4007346	34.01941413	Coral & Carbonate	Sample collected during ROV dive 7 north of Anacapa Island. Attempted sample was piece of carbonate. Sample appears to be a predominately coral attached to carbonate.
SR2301_ Anacapa_ Rk 5	7	1/9/2023	-119.4004607	34.02211564	Rock	During ROV dive 7, the rocky substrate where abundant corals and fauna were seen was sampled. The sample is bedded and dark (possibly shale or slate) and does not appear to be carbonate.
SR2301_ Anacapa_ Rk6	8	1/9/2023	-119.4329541	34.04894811	Carbonate	On ROV dive 8 north of Anacapa Island, carbonates were encountered both near to and coated with white bacterial mats. Sample was collected in an area without mats and appears to be predominantly carbonate with a large (>10 cm) mussel attached.
SR2301_ Anacapa_ Rk7	8	1/10/2023	-119.4321388	34.04912087	Carbonate	On ROV dive 8 north of Anacapa Island, carbonates were encountered both near and coated with white bacterial mats. Sample was collected in an area within several meters of bacterial mats and appears to be predominantly carbonate.
SR2301_ Anacapa_ Rk8	8	1/10/2023	-119.4301845	34.04891197	Carbonate	On ROV dive 8 north of Anacapa Island, carbonates were encountered both near and coated with white bacterial mats. Sample was collected in an area with several patchy bacterial mats. The sample appears to be predominantly carbonate with faunal boreholes.
SR2301_ Anacapa_ Rk9	10	1/10/2023	-119.4144738	34.02256968	Rock	ROV dive 10 targeted possible rock outcrops close to Anacapa Island. Sample targeted what appeared to be moderate/high relief outcrops. No bacterial mats were observed during this dive. The sample is not a carbonate, but is instead dark, dense, possibly metamorphic or volcanic, and does not have obvious layering/bedding.

Sample Name	Dive	Date	Latitude	Longitude	Material	Description
SR2301_ Anacapa_ Rk10	10	1/10/2023	-119.4133448	34.02248595	Rock	ROV dive 10 targeted possible rock outcrops close to Anacapa Island. Sample targeted what appeared to be moderate/high relief outcrops. No bacterial mats were observed during this dive. The sample is not a carbonate, but is instead dark, dense, possibly metamorphic or volcanic, and does not have obvious layering/bedding.
SR2301_ Anacapa_ Rk11	11	1/10/2023	-119.4123897	34.02343211	Rock	ROV dive 11 targeted a series of high-relief, bedded, outcrops. Sample was collected near a low-dipping outcrop. The sample is not a carbonate, but is instead dark, dense, possibly metamorphic or volcanic, and does not have obvious layering/bedding.
SR2301_ Anacapa_ Rk12	11	1/10/2023	-119.4102976	34.02359386	Rock	ROV dive 11 targeted a series of high-relief, bedded, outcrops. Sample was collected near a low-dipping outcrop that created a 1 to 2 meter high ledge in the seafloor. The sample is not a carbonate, but is instead dark, dense, possibly metamorphic or volcanic, and does not have obvious layering/bedding.
SR2301_ Anacapa_ Rk13	11	1/10/2023	-119.3992758	34.02238109	Carbonate	ROV dive 11 targeted a series of high-relief, bedded, outcrops. Sample was collected in a flat area of the seafloor with limited outcrops.
SR2301_ Anacapa_ Rk14	13	1/11/2023	-119.422481	34.04478247	Empty Vermetidae Tube	Sample was collected during ROV dive 13 within a local bathymetric low within a kilometer of the pockmarks explored in dive 3. The bathymetric low contained abundant biomaterial (appearing to be both terrestrial and marine in origin), possibly deposited during the recent and ongoing (at the time) storm. The sample appears to be a large empty calcareous tube of a Vermetidae. Tubeworms of this size are commonly found near active cold seeps.

Sample Name	Dive	Date	Latitude	Longitude	Material	Description
SR2301_ Anacapa_ Sd1	12	1/11/2023	-119.4224074	34.04469924	Sediment	Dark/stained seafloor sediment
SR2301_ Anacapa_ Sd2	13	1/11/2023	-119.4224408	34.04476961	Sediment	Large bacterial mat
SR2301_ Anacapa_ Sd3	13	1/11/2023	-119.4223311	34.04471477	Sediment	Large bacterial mat
SR2301_ Anacapa_ Sd4	13	1/11/2023	-119.422319	34.0447629	Sediment	Sediment under shell hash

II.4.d. List resulting publications, presentations, websites, etc. All publications must acknowledge the NOAA Office of Ocean Exploration and Research funding and be submitted to the NOAA Institutional Repository. Abstracts, publications, and other materials must be appended or linked to this report.

King, Roslynn, S. Constable, J. Maloney, and A.E. Gusick. (In review). CUESI: A near seafloor controlled-source electromagnetic system for shallow seabed characterization. In preparation for submission to *IEEE Journal of Oceanic Engineering*.

Gusick, Amy E., J. Maloney, R. King, A. Mendoza, S. Constable, S. Klotsko, T. Braje, J. Erlandson. 2024. *Identifying Submerged Cultural Maritime Landscapes Using New Technologies and Interdisciplinary Partnerships.* 56th Society for Historical and Underwater Archaeology, Oakland, California.

Gusick, Amy E. 2022. Plenary Speaker. *The Human Dimension: Cultural Heritage and the Channel Islands in the Decade of Ocean Science*. 10th California Islands Symposium, Ventura, California.

Gusick, Amy E. 2021. *Technological Advances in the Search for Submerged Cultural Landscapes of the Pacific Continental Shelf.* 2021 Australian Institute for Maritime Archaeology Conference, *Oceans of Heritage: The Next Decade*, Virtual.

Gusick, Amy E. 2020. *Rising Seas, Shrinking Islands, and Shifting Habitats: Paleocoastal Occupation on California's Islands*. Global Period Modern Lecture Series. California State University, Channel Islands.

Gusick, Amy E. 2020. *Migrations, Marginality, and Maritime Landscapes: A New World Paleocoastal Occupation*. University of California Los Angeles, Cotsen Institute of Archaeology.

King, R. B., & Constable, S. (2023). How low can you go: An investigation of depth sensitivity and resolution using towed marine CSEM systems. *Geophysical Prospecting*. https://doi.org/10.1111/1365-2478.13345

King, R. B., Constable, S., & Maloney, J. M. (2022). A case study in controlled source electromagnetism: Near seabed hydrocarbon seep systems of Coal Oil Point, California, USA. *Marine and Petroleum Geology*, *139*. https://doi.org/10.1016/j.marpetgeo.2022.105636

King, R., Constable, S., Gusick, A. E., & Maloney, J. M. (2022). Development of a High Resolution, Shallow Water CSEM System. *AGU Fall Meeting Abstracts*, *2022*, GP33A-04.

II.4.e. List the final data inventory, including a complete list of all data types collected (e.g., CTD, MBES, images). Describe the location and status of the data archive and/or sample storage and the plan for timely public access. If the data are/will be archived at an approved facility outside of NCEI, the URL link(s) to the data should be provided to OER.

The following data were generated as a result of this project:
•GIS spatial data layers of relative sea level-adjusted paleolandscape maps
•Edgetech 512i Chirp subbottom profiler data with real-time GPS readings
•SBP-29 subbottom profiler data with real-time GPS readings
•CSEM data with real time GPS readings
•Digital video and telemetry data collected during 13 ROV Beagle dives
•XRF and XRD data for samples
•Supplementary Data (different data types including photographs taken during analyses, archived
sample label records)
•Graphical figures synthesizing geophysical and sample data
•Peer-reviewed publications

Inventories for project data can be found and will be made available at multiple archives (Table 15) and copies of/links all data will be made available via file transfer and/or URL links to the data within a year of project completion.

Table 15. Project data and archives

Data	Date Available	Archive Location	URL
Subbottom (EdgeTech 512i & SBP-29)	TBD*	*Rolling Deck 2 Repository *NCEI *NSF Marine Geoscience Data Center	https://doi.org/10.7284/909883 https://www.ngdc.noaa.gov/ http://www.marine-geo.org/index.php
CSEM (Porpoise & CUESI)	TBD*	*SIO EM laboratory *NSF Marine Geoscience Data Center	https://scripps.ucsd.edu/marine-em-laboratory http://www.marine-geo.org/index.php
ROV Photos and Videos	TBD*	*NCEI	https://www.ngdc.noaa.gov/
Sample Data	TBD*	*FigShare *NCEI	https://figshare.com https://www.ngdc.noaa.gov

II.4.f. Note any major changes/adjustments to activities, expenditures, results, etc. reported in previously-submitted documents (e.g., Cruise Report, Semi-Annual Report).

While there were major adjustments to the project schedule and ground truthing for planned ROV targets, changes to expenditures and overall project plan were relatively minor.

Equipment Loss

Original planned subottom data collection on the R/V *Beyster* in Sep-Oct 2021 was delayed due to loss of subbottom towfish off the north shore of San Miguel Island at -120.398161 / 34.118014 in 70 m of ocean depth. We attempted a search and recovery mission on 10/01/2021 with a professional ROV operator from PRO-ROV, LLC. and again on 01/08/2023 with the ROV Beagle, but were unsuccessful. We were able to secure a subbottom cruise aboard the R/V *Shearwater* in March 2022, funded by BOEM. For this cruise, Klotsko provided her subbottom to complete the data collection and we used NOAA funding to ship the system from UNCW to SIO. The recovery mission and the additional shipping cost $10,044.

Cancellation of ROV cruise

We had scheduled the ROV sample cruise for April 2022 aboard the R/V *Sally Ride*. This large research vessel was to accommodate three related projects, as well as a classroom at sea. The ship time was funded by a combination of this NOAA OER grant with a UC Ship Funds grant based on a proposal submitted by collaborator King, who was a PhD student at the time. The Ship Funds grant offered extra days at sea and a collaborative effort with Scripps graduate students and researchers. It also offered training to graduate students that would serve as chief scientists aboard the cruise. However, two days prior to mobilization, SIO canceled the cruise due to an inability to hire qualified mariners for three positions on the ship crew. This was a result of lasting issues in the Mariner's job market due to mass exodus during the pandemic. Unfortunately, we had completed all logistics, including flying our ROV team and equipment in from Puerto Rico, where they were finishing another NOAA project. While SIO was able to reschedule the cruise for January 2023, we had to request a one year no cost extension on the NOAA Ocean Exploration grant and pay for the time and logistics of the ROV team. To compensate, SIO funded the majority of the January 2023 cruise, supporting all mobilization and demobilization days, as well as eight days at sea. The NOAA OER grant funded one extra day at sea aboard the R/V *Sally Ride*. This switch in cruise dates also caused a rescheduling for the ROV teams. We originally scheduled the Undersea Vehicle Program at UNCW for the work, but switched to MARE as the UNCW team was not available for our rescheduled dates. As we were not using UNCW in the future, we did cover their costs for travel, shipping expenses, and a fraction of their time up to this point in the project. MARE was more expensive than UNCW so we incurred extra costs for the ROV rental and operation, but saved a significant amount of funding for the ship rental as most costs were covered by SIO.

Weather issues

Storm conditions forced the initial 2023 cruise plan aboard the R/V *Sally Ride* to abandon all planned ROV survey areas with high probability of active tar seepage and instead focus on the area north of Anacapa Island which still had relatively calm conditions. This region has very limited available data outside of this study and so the seafloor substrate, fault trace locations, and general geology of the area are not well constrained. Because of the lack of baseline data, the initial ROV surveys focused on constraining the CSEM and acoustic signatures previously identified in the area.

II.4.g. Equipment inventory procured with grant funds and final disposition by NOAA on ownership.

No equipment was purchased during this project.

III. EVALUATION

III.1. Accomplishments – Explain special problems and discrepancies between scheduled and accomplished work

The most significant difference between scheduled and accomplished work was the planned sample collection from tar seeps. Our research identified numerous hydrocarbon targets, but we were able to sample from only one region due to weather issues described in section II.4.f. This investigation resulted in identification of a significant shallow water cold seep. All other planned data were successfully collected over three rather than the planned two research cruises.

III.2. Expenditures:

III.2.a. Describe original planned expenditures

Personnel: $0
Fringe Benefits: $0
Travel: $12,411
Equipment: $0
Supplies: $0
Contractual: $0
Construction: $0
Other: $321,046
Indirect Charges: $36,550
TOTAL: $370,807

III.2.b. Describe actual expenditures

Personnel: $0
Fringe Benefits: $0
Travel: $13,325.59
Equipment: $0
Supplies: $6,753.64
Contractual: $0
Construction: $0
Other: $305,434.38
Indirect Charges: $42,498.28
TOTAL: $368,011.89

Balance remaining: 2,795.11

III.2.c. Include a final budget table (OER template provided) with a column of original planned expenditures and a column of actual grant expenditures

NOAA Grant No.: NA20OAR0110428
Institution Name: Natural History Museum Los Angeles County
Lead PI: Amy Gusick
Report Period: 09/01/2020 - 08/31/2023
Award Period: 09/01/2020 - 08/31/2023
Award Amount: $370,807

	Planned Expenditures	Actual Expenditures	Difference
Salaries & Wages	$0	$0	$0
Staff Benefits	$0	$0	$0
Travel	$12,411	$13,325.59	$-914.59
Services	$0	$0	$0
Supplies	$0	$6,753.64	$-6,753.64
Equipment	$0	$0	$0
Other	$321,046	$305,434.38	$15,611.62
Indirect Cost	$36,550	$42,498.28	$-5,948.28
Total	**$370,807**	**$368,011.89**	**$2,795.11**

III.2.d. Explain special problems and discrepancies between planned and actual expenditures

The discrepancies are described in section II.4.f. All of the discrepancies were a result of the canceled April 2022 ROV cruise. The reduction in the cost in the Other category was a result of cost savings realized for the rescheduled January 2023 cruise that was supported by a Ship Fund grant through SIO. The increase in travel was also a result of the canceled original ROV cruise as we had all personnel and equipment on site, waiting to board the ship when it was canceled. Increase in supplies was due to purchasing of parts for manufacturing sampling equipment that was needed for the MARE ROV that the original UNCW ROV had as part of its sampling package. We also purchased a XRD-Mill McCrone for sample grinding precision. Increase in the indirect was a result of a rebudgeting from rental costs which are not subject to indirect and an increase in some shipping, travel, and supply costs that did incur indirect. We ultimately spent $2,795.11 less than awarded.

III.3. Next Steps:

III.3.a. Planned or expected outcomes (professional papers, presentations, etc.)

We will share results of this research with tribal partners as well as the broader scientific and layperson communities through peer reviewed papers and presentations. Initial planned presentations are at the Society for Historical Archaeology 2024 annual conference in a symposium hosted by NOAA OER. This research will also be showcased through outreach efforts from NHMLA, including an upcoming (January 2024) museum Fellow's event on museum deep time research. As this research is part of an ongoing research focus for the cultural landscapes of the Southern California Bight, it will be included in numerous presentations across disciplines, particularly considering the finding of the shadow water cold seep. We plan to publish the results of this finding in 2024 and expect that those data will be used for various other types of research on the nature of shallow water cold seeps.

III.3.b. Brief description of how project deliverables and outcomes contribute to societal and/or ecosystem well-being

Both the geophysical data as well as the cold seep habitat discovery provide critical data to reconstruct the paleogeography and paleoecology of the SCB region, as well as the current ecological conditions surrounding the cold seep and the supported organisms. The seismic and EM data help continued development of broad scale mapping of the continental shelf of the SCB and contribute to modeling efforts focused on definition of archaeological and biological sensitive landscapes. By mapping features important in recognizing archaeological and biological sensitive landscapes, these data provide important information to land management agencies who need to identify, document, and manage sensitive resources on landscapes under their purview. Additionally, the mapping of hydrocarbon on the continental shelf may help identify additional cold seeps, a sensitive habitat, as well as possible asphaltum deposits that may yield microfossil data to clarify paleoecology of the region. From a methods standpoint, this project contributes to the continual development of best practices in maritime archaeological research. The method of joint sonar/CSEM survey has shown to help facilitate target identification by providing additional data with which to consider seafloor features. This can reduce time and costs associated with sampling. By continuing to develop more sophisticated methods in underwater archaeology and exploration, partnering with interdisciplinary scientists, and participating in agency-academic cooperative projects, we stand at the cusp of better understanding submerged landscapes along the eastern Pacific Rim and around the world.

III.3.c. Brief description of needs and/or plans for additional work, if any (next project phase, new research questions, unaccomplished work, etc.)

This project has contributed to the continued research into the paleolandscape and paleoecology of the SCB region. This area is significant from biological, geological, paleontological, and cultural standpoint and our research agenda will continue to build upon our collected data and discoveries. This interdisciplinary project presents various research questions depending on the expertise and interests of the collaborators, and continues to advance methods for data collection. The next phase of the research will focus on those areas identified that harbor both sensitive archaeological and biological ecosystems, including the identified hydrocarbon signals that need further exploration and the paleoestuary and shell deposits identified with a previous project, but used with the current research for target identification and instrumentation testing. With this current project we have continued to identify areas important for both biological and geological studies in the region and have collected data that informs our search for submerged terminal Pleistocene landscapes that are sensitive for cultural material. Our datasets will continue to be evaluated for characterization of regional tectonics, in particular the nature of the Santa Rosa Island fault, and how this impacts landform development and movement through time. We will continue our analyses of the samples collected with the current research to determine the antiquity and nature of the shallow water cold seep and associated organisms. This find deserves particular attention and we plan to partner with marine biologists who specialize in these types of methane seeps. Importantly, we plan to seek additional funding and resources to groundtruth the ROV targets for hydrocarbon that we were unable to explore during this project. Some of these targets had characteristics of tar seeps, and we seek to sample these for microfossil identification. We will also continue to refine our developing methods for CSEM survey and associated instrumentation development. In particular, more testing of the CUESI system is needed across different seafloor characteristics. All of these tasks will help us to reach our goal of better understanding the paleolandscape and paleoecology of the unique SCB region and eventually identity, protect, and preserve underwater cultural landscapes.

Prepared By: Amy Gusick, Jillian Maloney, Roslynn King, Shannon Klotsko, Steve Constable, Aaron Celestian

Signature of Principal Investigator ____________________ Date 05/19/2024

References Cited

Adovasio, J.M. and A. Hemmings. 2009. Inner Continental Shelf Archaeology in the Northeast Gulf of Mexico. Paper Presented at the 74th Annual Meeting of the Society for American Archaeology, Atlanta.

Al-Zaidan, A. S. Y., Kennedy, H., Jones, D. A., & Al-Mohanna, S. Y. 2006. Role of microbial mats in Sulaibikhat Bay (Kuwait) mudflat food webs: evidence from δ13C analysis. *Marine Ecology Progress Series*, *308*, 27–36.

Baker, P. A., & Burns, S. J. 1985. Occurrence and Formation of Dolomite in Organic-Rich Continental Margin Sediments'. *AAPG Bulletin*, *69*(11), 1917–1930.

Blanton, D.B. and S.G. Margolin. 1994. *An Assessment of Virginia's Underwater Cultural Resources* (No. 3). Virginia Department of Historic Resources.

Boetius, A., & Wenzhöfer, F. 2013. Seafloor oxygen consumption fuelled by methane from cold seeps. In *Nature Geoscience* (Vol. 6, Issue 9, pp. 725–734). https://doi.org/10.1038/ngeo1926

Bowden, D. A., Rowden, A. A., Thurber, A. R., Baco, A. R., Levin, L. A., & Smith, C. R. 2013. Cold Seep Epifaunal Communities on the Hikurangi Margin, New Zealand: Composition, Succession, and Vulnerability to Human Activities. *PLoS ONE*, *8*(10). https://doi.org/10.1371/journal.pone.0076869

Braje, T.J., and J.M. Erlandson. 2008. Early Maritime Technology from Western San Miguel Island, California. *Current Research in the Pleistocene* 25:31–32.

Braje, T.J., J. Maloney, D. Ball, L. Davis, N. Driscoll, J. Dugan, J. M. Erlandson, A.E. Gusick, M. Page, L.L. Reeder-Myers, A. Nyers, and D. Schroeder. 2016. Mapping the Submerged Landscapes of Southern California and Oregon: Archaeological, Biological, and Geological Implications. Paper Presented at the 8th California Islands Symposium, Oxnard.

Braje et al. 2021. Archaeological and Biological Assessment of Submerged Landforms off the Pacific Coast of California and Oregon, USA. U.S. Department of the Interior, Bureau of Ocean Energy Management, Pacific OCS Region, Camarillo, CA. 171 p., plus appendices.

Clark, J., J.X. Mitrovica, and J. Alder. 2014. Coastal Paleogeography of the California–Oregon–Washington and Bering Sea Continental Shelves During the Latest Pleistocene and Holocene: Implications for the Archaeological Record. *Journal of Archaeological Science* 52:12-23.

Cohen, J.K. and Stockwell, J.W., 1999. CWP/SU: Seismic Unix Release 33: A free package for seismic research and processing, Center for Wave Phenomena. *Colo. Sch. of Mines, Golden*.

Constable, S. 2010. Ten years of marine CSEM for hydrocarbon exploration. *Geophysics*, *75*(5). https://doi.org/10.1190/1.3483451

Constable, S., and L.J. Srnka. 2007. An Introduction to Marine Controlled-source Electromagnetic Methods for Hydrocarbon Exploration. *Geophysics* 72(2):WA3-WA12.

Constable SC, Parker RL, Constable CG.1987. Occam's inversion: a practical algorithm for generating smooth models from electromagnetic sounding data. Geophysics 52(3):289–300

Dando, P. R. 2010. Biological communities at marine shallow-water vent and seep sites. In *The Vent and Seep Biota: Aspects from Microbes to Ecosystems* (pp. 333–378). http://www.springer.com/series/6623

Dibblee, T. W. 2001. *Geologic Map of Eastern Santa Cruz Island, Santa Barbara County, California*.

Dickens, G. R. 2003. Rethinking the global carbon cycle with a large, dynamic and microbially mediated gas hydrate capacitor. *Earth and Planetary Science Letters*, *213*(3–4), 169–183. https://doi.org/10.1016/S0012-821X(03)00325-X

Ding, H., & Valentine, D. L. 2008. Methanotrophic bacteria occupy benthic microbial mats in shallow marine hydrocarbon seeps, Coal Oil Point, California. *Journal of Geophysical Research: Biogeosciences*, *113*(1). https://doi.org/10.1029/2007JG000537'

El-khatib, N. 1997. A Fast and Accurate Method for Parameter Estimation of Archie Saturation Equation. *All Days*. https://doi.org/10.2118/37744-MS

Elvert, M., Suess, E., & Whiticar, M. J. 1999. Anaerobic methane oxidation associated with marine gas hydrates: superlight C-isotopes from saturated and unsaturated C 20 and C 25 irregular isoprenoids. In *Naturwissenschaften* (Vol. 86). Springer-Verlag.

Erlandson, J.M. 1994. Early Hunter-Gatherers of the California Coast. Springer, New York.

Erlandson, J.M. 2016. Seascapes of Santarosae: Paleocoastal Seafaring on California's Channel Islands. In, *Marine Ventures: Archaeological Perspectives on Human-Sea Relations*, edited by, H.B. Bjerck, H. M. Breivik, S. E. Fretheim, E. L. Piana, B.e Skar, A. M. Tivoli, J. Zangrando, pp. 317-327. Equinox Publishing, Sheffield

Erlandson, J. M., T. C. Rick, T. J. Braje, M. Casperson, B. Culleton, B. Fulfrost, Tracy Garcia, D. Guthrie, N. Jew, D. Kennett, M. L. Moss, L.Reeder, C. E. Skinner, J. Watts, L. M. Willis. 2011. Paleoindian Seafaring, Maritime Technologies, and Coastal Foraging on California's Channel Islands. *Science* 441:1181-1185.

Evans, A., N.C. Flemming, and J. Flatman (eds). 2014. *Prehistoric Archaeology of the Continental Shelf: A Global Review.* Springer, New York

Faught, M.K. 2002. Submerged Paleoindian and Archaic Sites of the Big Bend, Florida. *Journal of Field Archaeology* 29:273–290.

Faught, M.K. 2004. The Underwater Archaeology of Paleolandscapes, Apalachee Bay, Florida. *American Antiquity* 69:235–249.

Fillon, R.H., 2006. Glacioeustatic Sea Level, Gas Hydrate Stability, and a Late Pleistocene Shelf-edge Delta in the Northeast Gulf of Mexico: Environmental Factors Controlling Shelf-Margin Stability and the Probable Record for Pre-Clovis Man in North America, poster presented to the Geological Society of America Annual Meeting, Philadelphia.

Fischer, P.J., 1975. *Natural gas and oil seeps, Santa Barbara basin, California*. California State University, Department of Geosciences.

Garrison, E.G. 2000. A Geoarchaeological study of Prisoner's Harbor, Santa Cruz Island, Northern Channel Islands, California - Past Sea Levels and Delatic Deposits of an Insular Stream. In, *Proceedings of the 5th California Islands Symposium*, edited by, C.J. Donlan, B.R. Tershy, B.S. Keitt and B. Wood, pp. 531–540. Santa Barbara Museum of Natural History, Santa Barbara.

Grøn, O., Boldreel, L.O., Smith, M.F., Joy, S., Tayong Boumda, R., Mäder, A., Bleicher, N., Madsen, B., Cvikel, D., Nilsson, B. and Sjöström, A. 2021. Acoustic mapping of submerged stone age sites—a HALD approach. *Remote Sensing*, *13*(3), p.445.

Gusick, A.E. 2013. Early Maritime Hunter-Gatherer Occupation, Santa Cruz Island. In, *Small Islands, Big Implications: The California Channel Islands and their Archaeological Contribution*, edited by J. Perry and C. Jazwa, pp. 40-59. University of Utah Press, Salt Lake City.

Gusick, A.E. and M.K. Faught. 2011. Prehistoric Underwater Archaeology: A Nascent Subdiscipline Critical to Understanding Early Coastal Occupations and Migration Routes. In, *Trekking the Shore: Changing Coastlines and the Antiquity of Coastal Settlement,* edited by N. Bicho, J. Haws, L.G. Davis, pp. 27-50. Springer, New York.

Gusick, A.E. and J.M. Erlandson. 2019. Paleocoastal Landscapes, Marginality, and Initial Settlement of California's Islands. In, An *Archaeology of Abundance: Re-evaluating the Marginality of California's Islands*, edited by K. Gill, J. Erlandson, and M. Fauvelle, pp. 59-97. University of Florida Press, Gainesville.

Gusick, A.E., J. Maloney, R. King, and T. Braje. 2019. Emerging Technologies in the Search for Submerged Cultural Landscapes of the Pacific Continental Shelf. In, *Proceedings of the 50th Annual Offshore Technology Conference*, p.1-14. OTC, Houston.

Halligan, J.J., M.R. Waters, A. Perrotti, I.J. Owens, J.M. Feinberg, M.D. Bourne, B. Fenerty, B. Winsborough, D. Carlson, D.C. Fisher, and T.W. Stafford. 2016. Pre-Clovis Occupation 14,550 Years Ago at the Page-Ladson Site, Florida, and the Peopling of the Americas. *Science Advances 2*(5):p.e1600375.

Henkart, P., 2006. SIOSEIS. *Scripps Inst. of Oceanogr., Univ. of San Diego, San Diego, Calif.*

Hinrichs, K. U., Hayes, J. M., Sylva, S. P., Brewer, P. G., & DeLong, E. F. 1999. Methane-consuming archaebacteria in marine sediments. *Nature*, *398*(6730), 802–805.

Hornafius, J. S., Quigley, D., & Luyendyk, B. P. 1999. The world's most spectacular marine hydrocarbon seeps (Coal Oil Point, Santa Barbara Channel, California): Quantification of emissions. *Journal of Geophysical Research: Oceans*, *104*(C9), 20703–20711. https://doi.org/10.1029/1999jc900148

Jessen, G. L., Pantoja, S., Gutiérrez, M. A., Quiñones, R. A., González, R. R., Sellanes, J., Kellermann, M. Y., & Hinrichs, K. U. 2011. Methane in shallow cold seeps at Mocha Island off central Chile. *Continental Shelf Research*, *31*(6), 574–581. https://doi.org/10.1016/j.csr.2010.12.012

Johnson, K.M. and Grimm, K.A. 2001. Opal and organic carbon in laminated diatomaceous sediments: Saanich Inlet, Santa Barbara Basin and the Miocene Monterey Formation. *Marine Geology*, *174*(1-4), pp.159-175.

Key K. 2016. MARE2DEM: a 2-D inversion code for controlled-source electromagnetic and magnetotelluric data. Geophys J Int 207(1): 571–588

King, R. B. 2022. *Controlled-Source Electromagnetic Studies of the Southern California Continental Shelf*. University of California, San Diego. King, R. B., & Constable, S. 2023. How low can you go: An investigation of depth sensitivity and resolution using towed marine CSEM systems. *Geophysical Prospecting*. https://doi.org/10.1111/1365-2478.13345

King, R., J.M. Maloney, S. Constable, A.E. Gusick, T. Braje, D. and Ball. 2018. Feasibility of Detecting Submerged Landforms and Archaeological Resources Using Controlled Source Electromagnetic Methods. In, *AGU Fall Meeting Abstracts*.

King, R. B., Constable, S., & Maloney, J. M. 2022. A case study in controlled source electromagnetism: Near seabed hydrocarbon seep systems of Coal Oil Point, California, USA. *Marine and Petroleum Geology*, *139*. https://doi.org/10.1016/j.marpetgeo.2022.105636

King, R.B., Danskin, W.R., Constable, S. & Maloney, J.M. 2022b. Identification of fresh submarine groundwater off the coast of San Diego, USA, using electromagnetic methods. *Hydrogeology Journal*, 30, 965–973. https://doi.org/10.1007/s10040-022-02463-y

King, R., Constable, S., Gusick, A. E., & Maloney, J. M. 2022. Development of a High Resolution, Shallow Water CSEM System. *AGU Fall Meeting Abstracts*, *2022*, GP33A-04.

Kvenvolden, K. A., & Rogers, B. W. 2005. Gaia's breath - Global methane exhalations. *Marine and Petroleum Geology*, *22*(4 SPEC. ISS.), 579–590. https://doi.org/10.1016/j.marpetgeo.2004.08.004

Laws, A., J. Maloney, S. Klotsko, A.E. Gusick, T. Braje, D. Ball. 2019. Submerged Paleoshoreline Mapping Using High-Resolution Chirp Sub-Bottom Data, Northern Channel Islands Platform, California, USA., *Quaternary Research* 1-22:In Press, doi: 10.1017/qua.2019.34

Leifer, I., Kamerling, M.J., Luyendyk, B.P. and Wilson, D.S., 2010. Geologic control of natural marine hydrocarbon seep emissions, Coal Oil Point seep field, California. *Geo-Marine Letters*, *30*, pp.331-338.

Levin, L. A., Baco, A. R., Bowden, D. A., Colaco, A., Cordes, E. E., Cunha, M. R., Demopoulos, A. W. J., Gobin, J., Grupe, B. M., Le, J., Metaxas, A., Netburn, A. N., Rouse, G. W., Thurber, A. R., Tunnicliffe, V., Van Dover, C. L., Vanreusel, A., & Watling, L. 2016. Hydrothermal vents and methane seeps: Rethinking the sphere of influence. *Frontiers in Marine Science*, *3*(MAY). https://doi.org/10.3389/fmars.2016.00072

Lorenson, T.D., Hostettler, F.D., Rosenbauer, R.J., Peters, K.E., Dougherty, J.A., Kvenvolden, K.A., Gutmacher, C.E., Wong, F.L. and Normark, W.R., 2009. *Natural offshore oil seepage and related tarball accumulation on the California coastline—Santa Barbara Channel and the Southern Santa Maria Basin; source identification and inventory* (No. 2009-1225). US Geological Survey.

Lv, Y., Yang, S., Xiao, X., Zhang, Y., María, E., & Zambrano, M. 2022. *Stimulated Organic Carbon Cycling and Microbial Community Shift Driven by a Simulated Cold-Seep Eruption*. https://journals.asm.org/journal/mbio

Maloney, J.M., S.A. Klotsko, A.E. Gusick, T.J. Braje, D. Ball, L. Davis, and A. Nyers. 2017. Paleodrainage Morphology During Glacial-Interglacial Cycles in the Northern Channel Islands, California, AGU Fall Meeting, New Orleans, LA.

Maloney, J.M., S. Klotsko, H. Tahiry, A. Laws, A.E. Gusick, T. Braje, and D. Ball. 2018. December. Shelf stratigraphy on the Northern Channel Islands platform, offshore southern California. In *AGU Fall Meeting Abstracts*, Washington DC.

Merwin, D. 2006. Submerged Prehistoric Archaeological Deposits in the New York Bight, poster presented to the annual meeting of the Geological Society of America, Philadelphia.

Meyer D, Constable S, Key K. 2011. Broad-band waveforms and robust processing for marine CSEM surveys. Geophys J Int 184(2):689– 698.https://doi.org/10.1111/j.1365-246X.2010.04887.x

Milkov, A. V., Sassen, R., Apanasovich, T. V., & Dadashev, F. G. 2003. Global gas flux from mud volcanoes: A significant source of fossil methane in the atmosphere and the ocean. *Geophysical Research Letters*, *30*(2). https://doi.org/10.1029/2002GL016358

Montagna, P. A., Bauer, J. E., Toal, J., Hardin, D., & Spies, R. B. 1987. Temporal variability and the relationship between benthic meiofaunal and microbial populations of a natural coastal petroleum seep. *Journal of Marine Research*, *45*, 761–789.

Mozley, P. S., & Burns, S. J. 1993. Oxygen and carbon isotopic composition of marine carbonate concretions: an overview. *Journal of Sedimentary Research*, *63*(1), 73–83.

Noble-James, T., Judd, A., Diesing, M., Clare, D., Eggett, A., Silburn, B., & Duncan, G. 2020. Monitoring shallow methane-derived authigenic carbonate: Insights from a UK Marine Protected Area. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *30*(5), 959–976. https://doi.org/10.1002/aqc.3296

Paul, B. G., Ding, H., Bagby, S. C., Kellermann, M. Y., Redmond, M. C., Andersen, G. L., & Valentine, D. L. 2017. Methane-oxidizing bacteria shunt carbon to microbial mats at a marine hydrocarbon seep. *Frontiers in Microbiology*, *8*(FEB). https://doi.org/10.3389/fmicb.2017.00186

Rick, T. C., and J. M. Erlandson. 2012. Kelp Forests, Coastal Migrations, and the Younger Dryas: Late Pleistocene and Earliest Holocene Human Settlement, Subsistence, and Ecology on California's Channel Islands. In, *Hunter-Gatherer Behavior: Human Response during the Younger Dryas*, edited by M.I. Eren, pp. 79–110. Left Coast Press, Walnut Creek.

Rick, T.C., Erlandson, J.M., Jew, N.P. and Reeder-Myers, L.A., 2013. Archaeological survey, paleogeography, and the search for Late Pleistocene Paleocoastal peoples of Santa Rosa Island, California. *Journal of Field Archaeology*, *38*(4), pp.324-331

Ruff, S. E., Biddle, J. F., Tesked, A. P., Knittel, K., Boetius, A., & Ramette, A. 2015. Global dispersion and local diversification of the methane seep microbiome. *Proceedings of the National Academy of Sciences of the United States of America*, *112*(13), 4015–4020. https://doi.org/10.1073/pnas.1421865112

Sherman D, Kannberg P, Constable S. 2017. Surface towed electromagnetic system for mapping of subsea Arctic permafrost. Earth Planet Sci Lett 460:97–104.

Tahiry, H., J. Maloney, S. Klotsko, A.E. Gusick, T. Braje, and D. Ball. 2018. Examining Paleodrainage Evolution since the Last Glacial Maximum, Northern Channel Islands, California, USA. Presented at the *Geological Society of American 2018 Annual Meeting,* Indianapolis.

Thiel, V., Peckmann, J. J., Seifert, R., Wehrung, P., Reitner, J., & Michaelis, W. 1999. *Highly isotopically depleted isoprenoids: Molecular markers for ancient methane venting*.

Tunnicliffe, V., Juniper, S. K., & Sibuet, M. (2003). Reducing environments of the deep-sea floor. In P. A. Tyler (Ed.), *Ecosystems of the Deep Oceans* (pp. 81–110). Elsevier.

Tweet, J. S., Santucci, V. L., Convery, K., Hoffman, J., & Kirn, L. 2020. *Channel Islands National Park: Paleontological Resource Inventory (Public Version)*.

US Geological Survey and California Geological Survey. 2006. Quaternary fault and fold database for the United States. *US Geological Survey*.

Van Dover, C. L., & Fry, B. 1994. Microorganisms as food resources at deep-sea hydrothermal vents. *Limnology and Oceanography*, *39*(1), 51–57. https://doi.org/10.4319/lo.1994.39.1.0051

Weitemeyer, K. A., Constable, S. C., Key, K. W., & Behrens, J. P. 2006. First results from a marine controlled-source electromagnetic survey to detect gas hydrates offshore Oregon. *Geophysical Research Letters*, *33*(3). https://doi.org/10.1029/2005GL024896

Weitemeyer, K., S. Constable, D. Shelander, and S. Haines. 2017. Mapping the Resistivity Structure of Walker Ridge 313 in the Gulf of Mexico Using the Marine CSEM method. *Marine and Petroleum Geology* 88:1013-1031.

Winsauer, W. O., Shearin Jr., H. M., Masson, P. H., & Williams, M. 1952. Resistivity of Brine-Saturated Sands in Relation to Pore Geometry1. *AAPG Bulletin*, *36*(2), 253–277. https://doi.org/10.1306/3D9343F4-16B1-11D7-8645000102C1865D

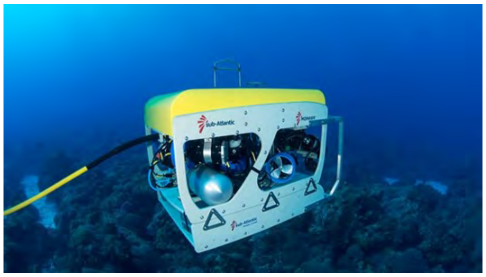
APPENDIX A

Tribal Communication & Internship

Native American Outreach
Paleolandscapes, Paleoecology, and Cultural Heritage on the Southern California Continental Shelf, #NA20OAR0110428
Gusick

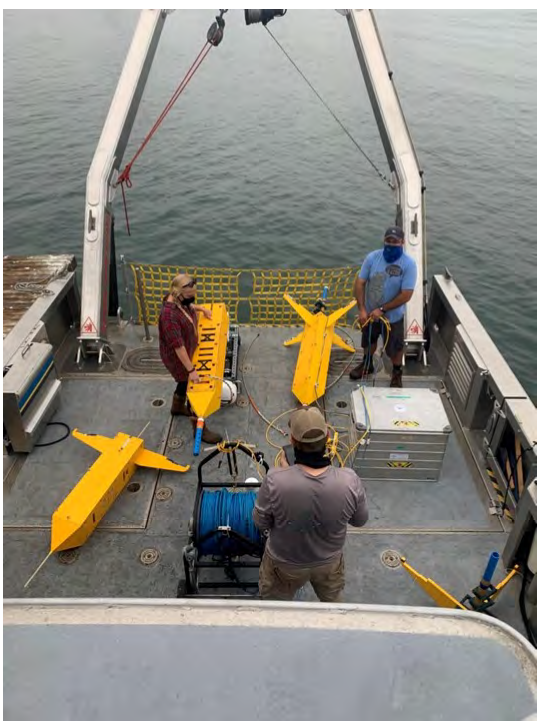
Tribe/Band	Affiliation	Email Sent	Mail?	Follow up	Response
Barbareno/Ventureno Band of Mission Indians Julie Tumamait-Stenslie, Chairperson 365 North Poli Ave, Ojai, CA, 93023 Phone: (805) 646 - 6214 jtumamait@hotmail.com	Chumash (non-federal tribe)	3/16/2021		4/9/2021	April 9: Spoke with Julie by phone and she is intersted in the project, particuarly because of the proposed wind farm off Vandeberg and the possiblity that underwater cultural work should be considered there.
Santa Ynez Band of Chumash Indians Kenneth Kahn, Chairperson P.O. Box 517, Santa Ynez, CA, 93460 Phone: (805) 688 - 7997 Fax: (805) 686-9578 kkahn@santaynezchumash.org	Chumash (federal tribe)	Dec. 2020		Continual	Feb. 16, 2021: Met with elders coucil - no questions - asked for flyer for internship - Nakia Zavalla is my contact Mar. 23, 2021: follow up call with Nakia April-June 2021: continual contact with Nakia: intern and project Andy Martinez is project intern - joined on geophysical and ROV cruises
Chumash Council of Bakersfield Julio Quair, Chairperson 729 Texas Street, Bakersfield, CA, 93307 Phone: (661) 322 - 0121 chumashtribe@sbcglobal.net	Chumash (non-federal tribe)	3/22/2021	3/23/2021		Email did not go through - mailed letter No response by June 2, 2021
Coastal Band of the Chumash Nation Mariza Sullivan, Chairperson P. O. Box 4464, Santa Barbara, CA, 93140 Phone: (805) 665 - 0486 cbcntribalchair@gmail.com	Chumash (non-federal tribe)	3/22/2021		6/2/2021	No response by June 2, 2021
Barbareno Band of Chumash Indians Eleanor Fishburn (nee Arellanes), Chairperson PO Box 5687, Ventura, CA, 93005 Phone: (805) 701 - 3246 eleanor@spiritinthewind.net	Chumash (non-federal tribe)	3/22/2021		6/2/2021	No response by June 2, 2021
Northern Chumash Tribal Council Fred Collins, Spokesperson P.O. Box 6533, Los Osos, CA, 93412 Phone: (805) 801 - 0347 fcollins@northernchumash.org	Chumash (non-federal tribe)	3/22/2021		6/2/2021	No response by June 2, 2021
Chumash Council Mark Vigil, Chief 1030 Ritchie Road, Grover Beach, CA, 93433 Phone: (805) 481 - 2461 Fax: (805) 474-4729	Chumash (non-federal tribe)	None	3/23/2021	6/2/2021	No email - mailed letter No response by June 2, 2021
NOAA Marine Sanctuary Chumash Working Group Eva Pagaling and Tano Cabugos evalani4@gmail.com; tano.wishtoyo@gmail.com		3/16/2021		4/23/2021	April 23: Eva contacted me about the project and the possibility of taking the intern position. She spoke with Tano and she will update him after her and I meet. June 2: Emailed Eva back to arrange a call Eva joined on Sep 2021 geophysical cruise

Marine Archaeology Internship



Internship Program

The Natural History Museum of Los Angeles County is offering one paid internship for 2021-2022. You will join the project *Paleolandscapes, Paleoecology, and Cultural Heritage on the Southern California Continental Shelf.* Using both traditional (sub-bottom sonar) and emerging methods (controlled source electromagnetic technology), you will join a team that will map a portion of the seafloor around the Northern Channel Islands and adjacent California mainland to identify features that may have once attracted human occupation when this region was above sea level. Features like ancient channels and estuaries as well as tar seep deposits will be explored and sampled with a remotely operated vehicle. These findings will be incorporated into existing maps and models to improve understanding of the project area's ancient landscape and how it changed over time.



Who: Motivated student or non-student, who is 18-years of age or older, interested in marine science, and specifically in marine archaeology

What: Paid (stipend) internship

When: July 2021-August 2022

Where: Natural History Museum of Los Angeles County (host) / will include participation in research cruises off Southern California

Contact the project director for more information:
Dr. Amy E. Gusick
Department of Anthropology
Natural History Museum Los Angeles
agusick@nhm.org

Project Partners

Natural History Museum Los Angeles County
La Brea Tar Pits & Museum
Scripps Institution of Oceanography UCSD
San Diego State University 1897
University of Oregon
UNCW University of North Carolina Wilmington

Funded by

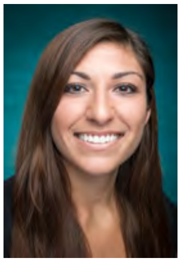
NOAA Ocean Exploration and Research

Project Leads

Dr. Amy E. Gusick earned her Ph.D. from University of California, Santa Barbara and is currently the Associate Curator for Archaeology at the Natural History Museum Los Angeles. Her research interests include human-environment dynamics, the development of maritime societies, peopling of the Americas, and hunter-gatherer subsistence and settlement. She uses both terrestrial and underwater archaeological methods in her research, and designs projects focused on early human coastal migration and settlement and the effects of environmental stress on late Pleistocene and early Holocene human groups along the Pacific Rim.

Dr. Jillian Maloney earned her Ph.D. from Scripps Institution of Oceanography at University of California, San Diego and is currently an Associate Professor in the Department of Geological Sciences at San Diego State University. Her research combines geophysical data including seismic reflection, multibeam bathymetry, and sidescan sonar with sediment analysis to understand tectonics and sediment processes on and beneath the seafloor and in coastal areas. She also studies submarine earthquakes and landslides and is interested in the geologic aspects of ecosystems and how geology can impact habitats.

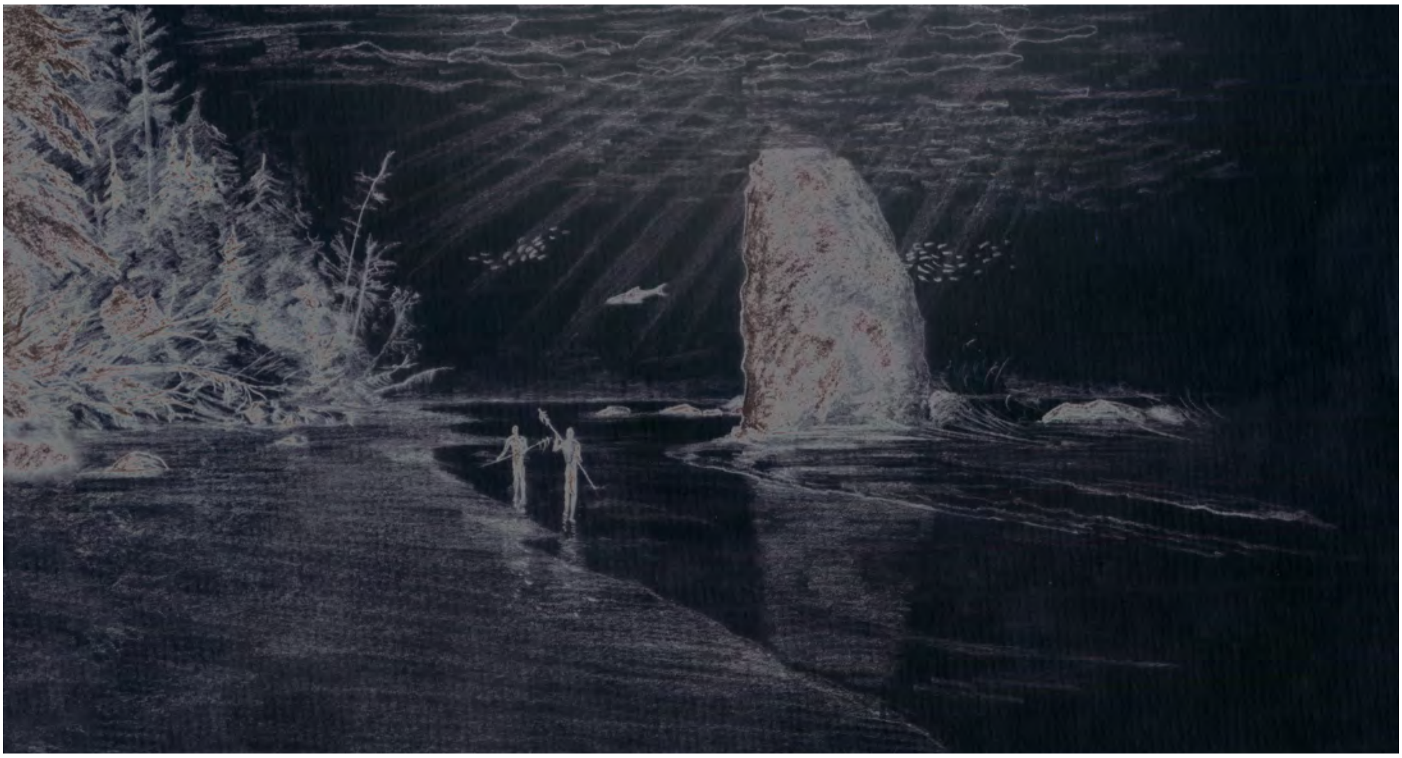
Dr. Todd Braje earned his Ph.D. from the University of Oregon and is currently Professor of anthropological archaeology in the Department of Anthropology at San Diego State University. He specializes in long-term human-environmental interactions, the archaeology of maritime societies, historical ecological approaches to understanding coastal hunter-gatherer-fishers, and the peopling of the New World.



Dr. Shannon Klotsko earned her Ph.D. from Scripps Institution of Oceanography at University of California, San and is currently an Assistant Professor of Geology in the Department of Earth and Ocean Sciences at University of North Carolina Wilmington. She uses seafloor mapping tools (multibeam bathymetry, sidescan sonar) and high resolution subbottom data (Chirp), along with sediment cores to study continental margin evolution during the late Quaternary and understand the impacts of processes such as sea level fluctuations, tectonics, and climate.

APPENDIX B

Artist Report



" OCEAN LINES "

Alejandro Cano-Lasso

December 2023

In January 2023, a comprehensive survey of the seabed in three distinct regions of the Southern California Bight—offshore San Dieguito Lagoon, Anacapa Island, and Goleta Slough—was conducted using a high-resolution sub-bottom profiler aboard the R/V Sally Ride from the Scripps Institution of Oceanography. These surveys, integral to the SEASCAPES research cruise, aim to establish baseline studies for paleo-cultural landscapes along the continental shelf of the Southern California Coast. The rock and sediment patterns captured in the imagery of various transects evoke remnants of coastal environments submerged under the sea due to rising ocean levels 20,000 to 8,000 years ago.

Transect	Length (m)	Initial Z (m)	Final Z (m)	Initial coordinates	Final coordinates	Date	Initial time	Final time
San Dieguito 1	1410	35	36	32 58.4393N 117 17.7103W	32 57.6666N 117 17.6031W	01/04/2023	20:34	20:48
San Dieguito 2	4420	45.7	46.3	32 57.3443N 117 17.8696W	32 59.6299N 117 18.2998W	01/04/2023	19:04	19:38
San Dieguito 3	1550	51	48.5	32 58.0976N 117 18.1101W	32 58.9645N 117 18.2115W	01/05/2023	17:01	17:11
San Dieguito 4	3210	56.7	54.4	32 57.3561N 117 18.2165W	39 59.1135N 117 18.5691W	01/04/2023	21:11	21:38
San Dieguito 5	3340	58.2	68	32 59.0991N 117 18.7366W	32 57.2174N 117 18.4590W	01/04/2023	21:42	22:11
San Dieguito 6	795	70.4	74	32 58.8004N 117 18.9528W	32 58.3680N 117 18.8778W	01/04/2023	20:12	20:19
Anacapa 1	6120	69.6	54.6	34 1.5539N 119 26.8591W	34 1.2238N 119 22.9285W	01/06/2023	18:03	18:51
Anacapa 2	4580	59.9	79.9	34 1.5658N 119 22.6471W	34 1.8699N 119 25.5892W	01/06/2023	18:59	19:36
Anacapa 3	4510	81.6	80.5	34 2.3059N 119 25.6437W	34 2.0150N 119 22.7548W	01/06/2023	19:47	20:21
Anacapa 4	4730	79	79.6	34 2.4134N 119 22.6797W	34 2.6828N 119 25.6169W	01/06/2023	20:31	21:09
Anacapa 5	4310	85	97.9	34 3.1022N 119 25.5403W	34 2.9083N 119 22.7293W	01/06/2023	21:17	21:53
Goleta 1	4480	51	41.4	34 23.3278N 119 49.7232W	34 23.3898N 119 46.8122W	01/08/2023	0:45	1:21
Goleta 2	3910	50.7	55.6	34 23.0955N 119 47.2795W	34 23.1403N 119 49.7977W	01/08/2023	0:14	0:42
Goleta 3	3870	61.2	55.2	34 22.8601N 119 49.7398W	34 22.9049N 119 47.2412W	01/07-08/2023	23:40	0:09
Goleta 4	4610	65.5	64.2	34 22.6060N 119 49.4514W	34 22.6080N 119 49.7750W	01/07/2023	23:30	23:34
Goleta 5	9210	77.2	63.9	34 22.2224N 119 52.7019W	34 22.4109N 119 46.7935W	01/07/2023	21:45	22:53

Table showing the transect lines and data used in this project

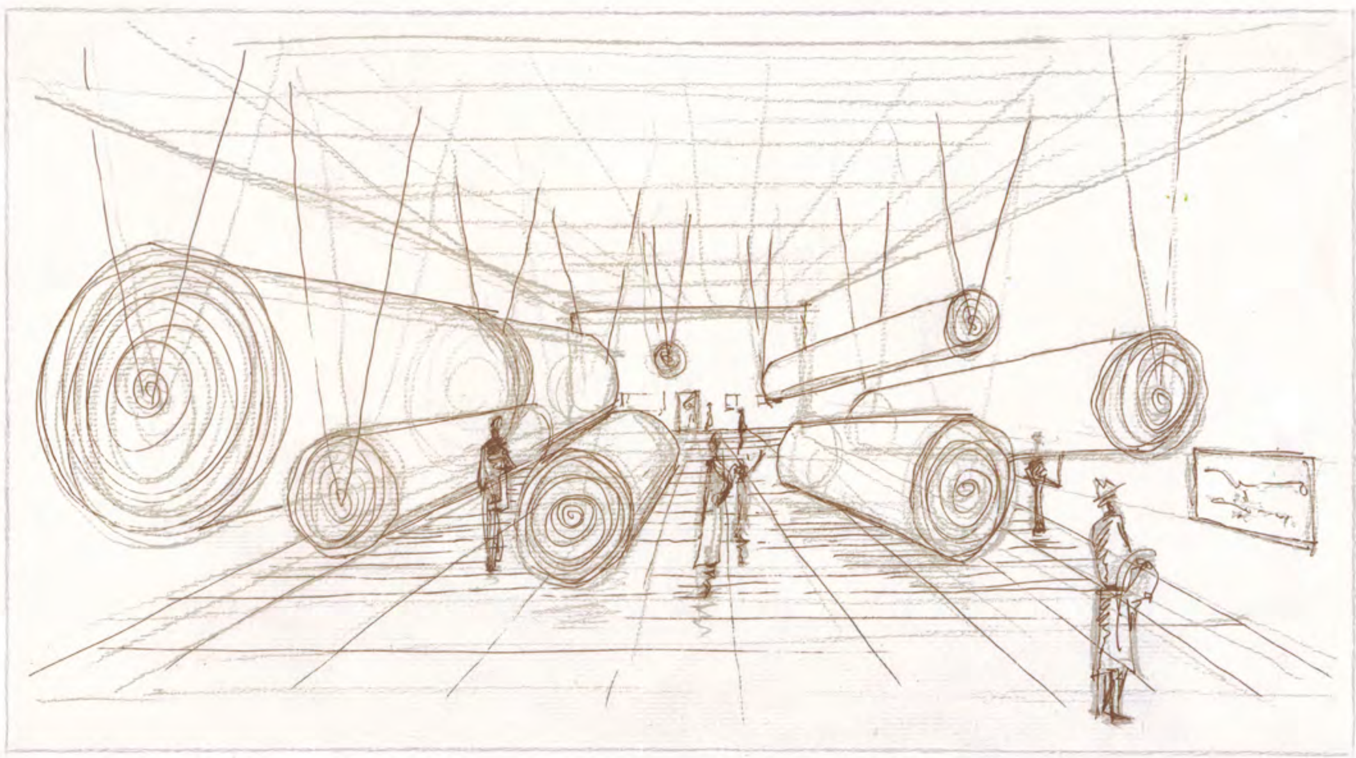
The artworks, gathered under the series 'Ocean Lines,' build upon the art of Piero Manzoni. In his line series from the 1950s, the conceptual artist hand-printed a single line of ink onto rolls of paper. These lines are encased in cardboard tubes, deliberately concealing their contents from the viewer. In the artist's words, these lines 'do not measure meters' but represent the beginning of an infinite series of unlimited extension.

Four 'lines of infinite length' from 'Linee' series by Piero Manzoni, 1959, Fondazione Piero Manzoni, Milano (left). Manzoni, making Line of m 7.200, Herning (Denmark), 4 July 1960, photographed by Ole Bagger. Photo: © HEART, Herning Museum of Contemporary Art, Herning / Herning Artmuseum / Fondazione Piero Manzoni, Milano (right).

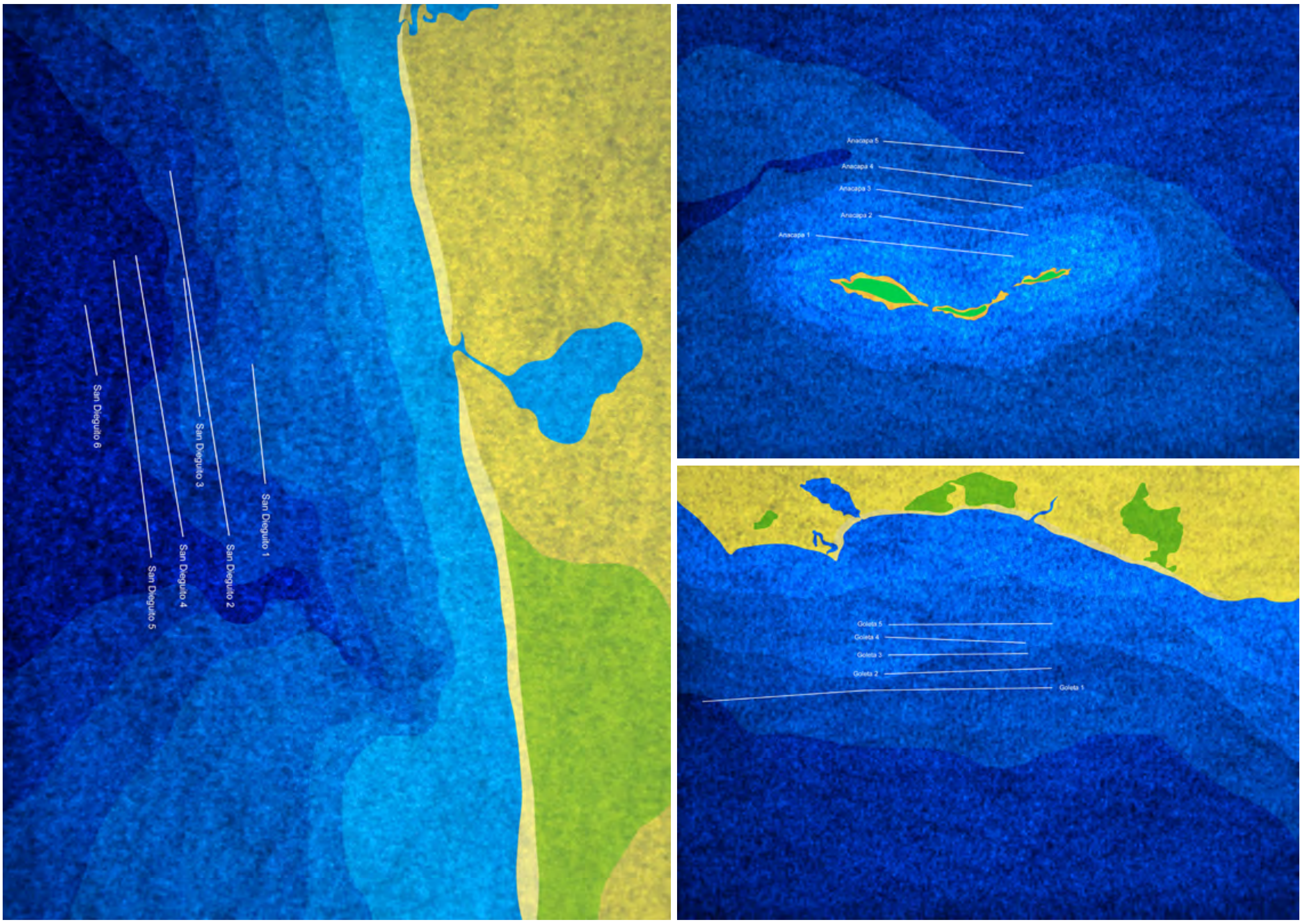
In this project, echograms from 16 transects are plotted using Konsberg SBP 27 software. The resulting images, depicting the seabed profile plus an additional three to five meters of sub-bottom, are printed life-size on industrial rolls of paper. Given the large extent of the transects and the limited resolution of the echograms, the prints become an abstract representation of the ocean floor. Every transect is individually rolled and wrapped, and inscribed with relevant data, including recording times, coordinates, and depths. During the transient and ephemeral moment of printing, an aspect of the ocean floor is unveiled.

The conceptual attributes of this project, however, are more comprehensively understood within the exhibition space. The suspended large rolls of paper serve as remnants of a specific event that occurred at a particular time and place. Even though the imaging of the 'unknown' remains distorted and hidden from view, these artifacts bear witness to the efforts of scientific exploration. They are a volumetric expression of the data contained in the image and label; tangible objects whose ostensible size challenges the viewer's imagination. Unlike Manzoni's Line series, these 'Ocean Lines' not only capture but also define finite time, real distance, and space.

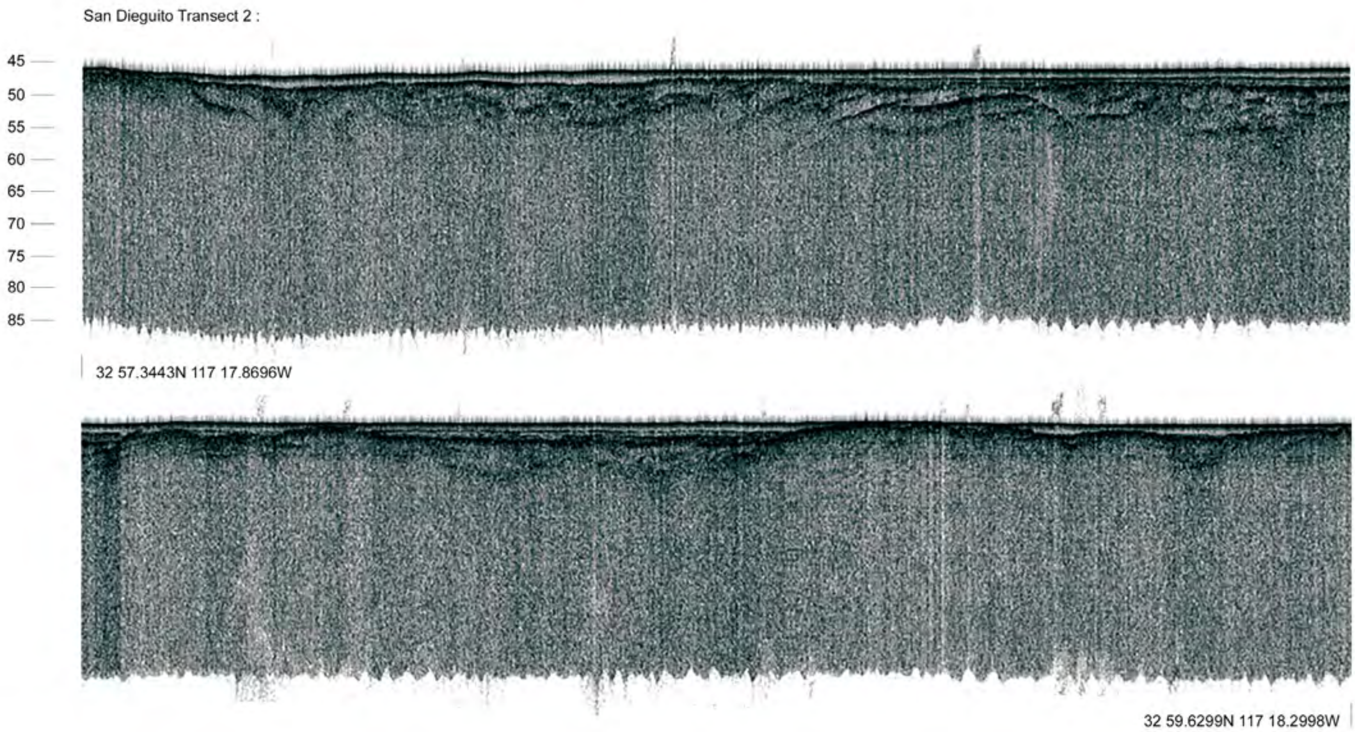
Sketches, maps, and illustrations executed in collaboration with scientists from the SEASCAPES project are exhibited alongside the 'Ocean Line' series, to encompass other aspects of research within the project and effectively illustrate the multidisciplinary character of ocean exploration.



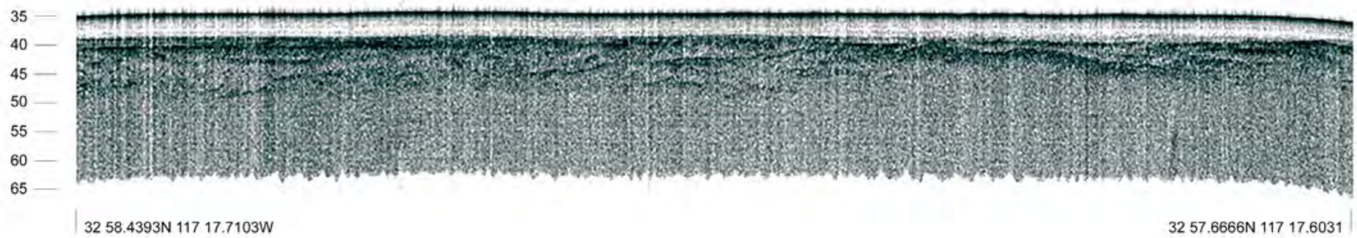
Concept sketch showing the large rolls of paper, printed with the transect data, in the exhibition space.



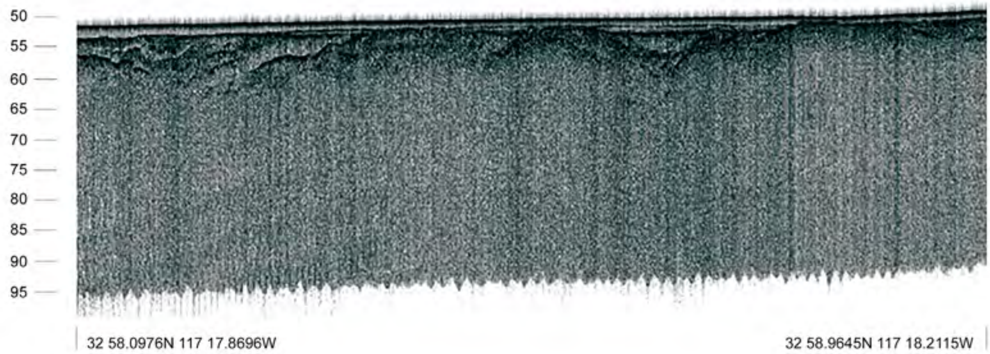
Three maps - San Dieguito, (left), Anacapa (upper right), Goleta (lower right) - showing the line transects selected for this project. Sixteen transects (bellow).



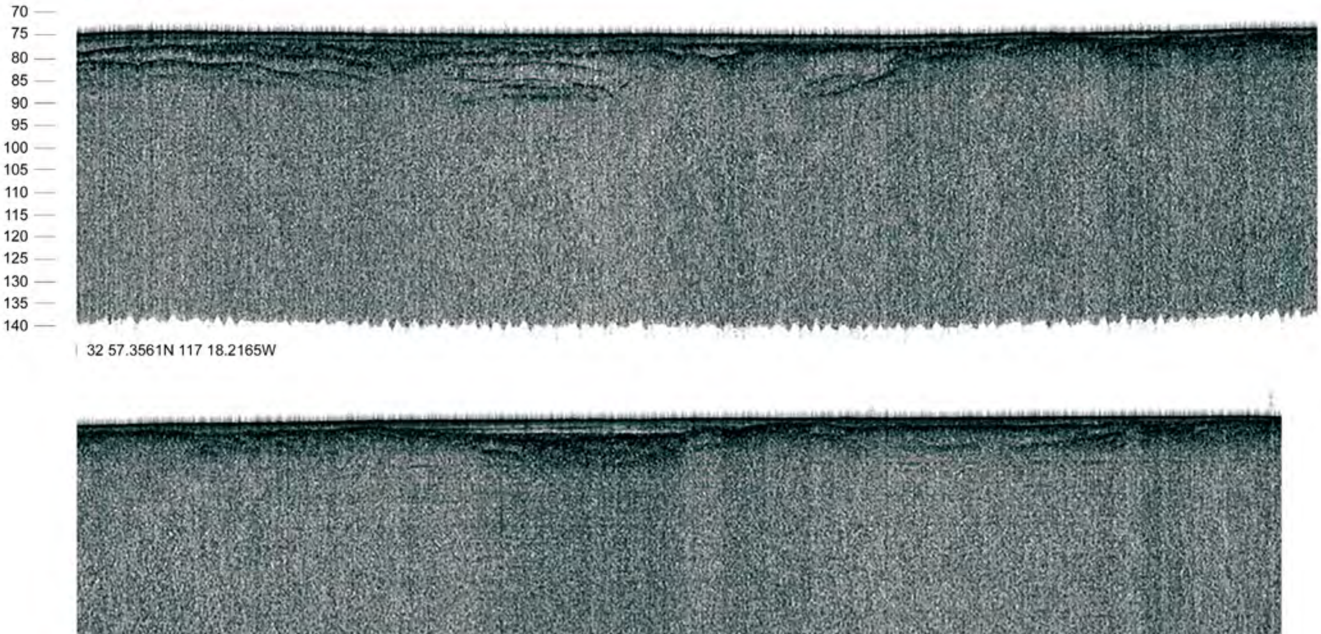
San Dieguito Transect 1 :



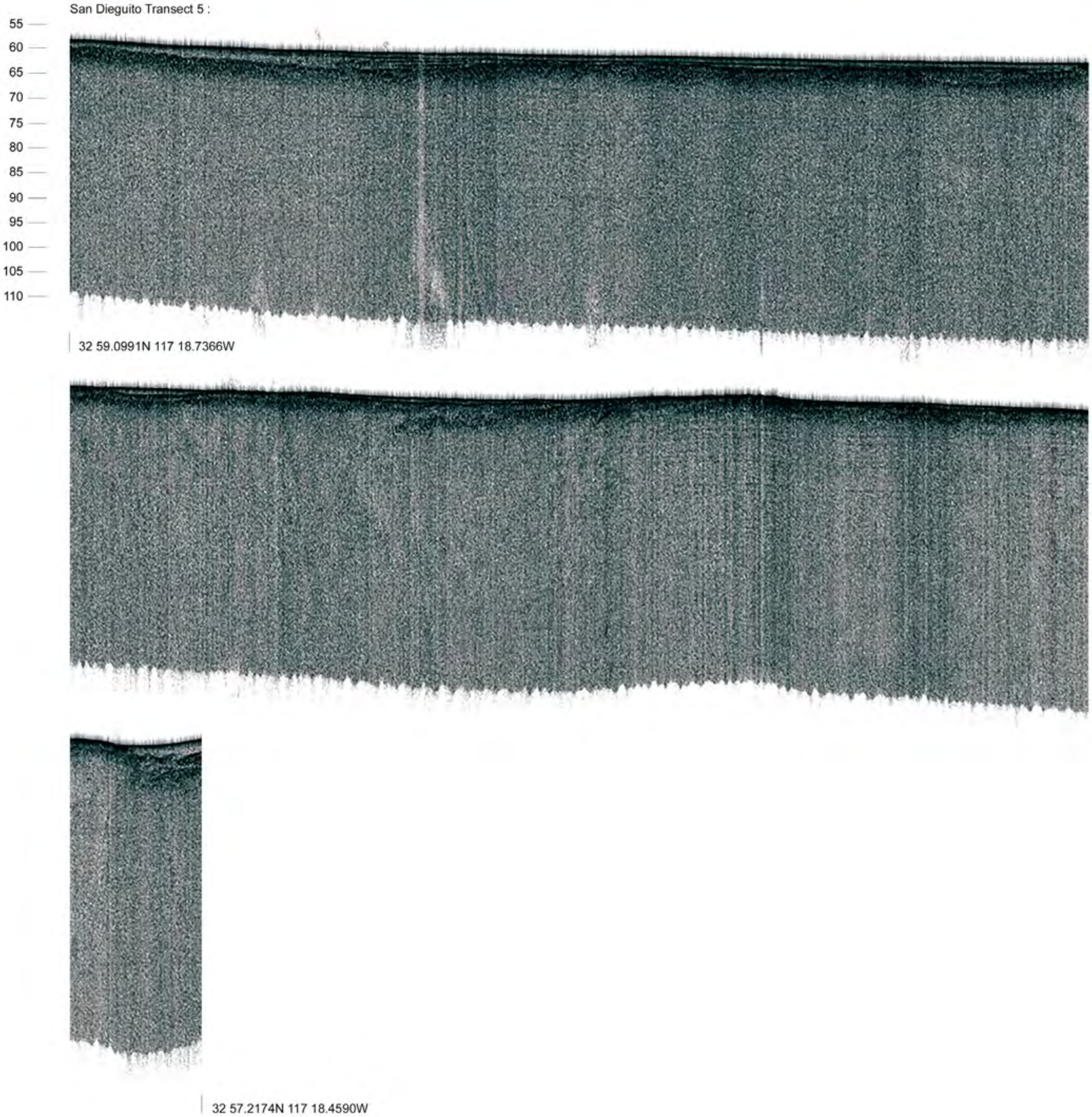
San Dieguito Transect 3 :



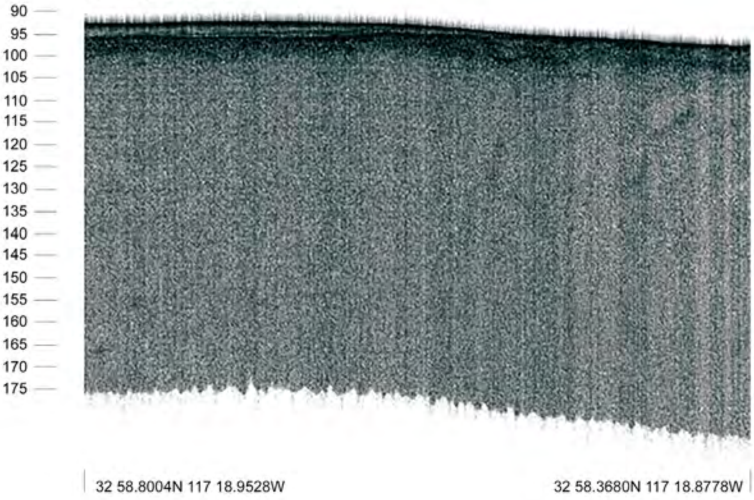
San Dieguito Transect 4 :



San Dieguito Transect 5 :



San Dieguito Transect 6 :



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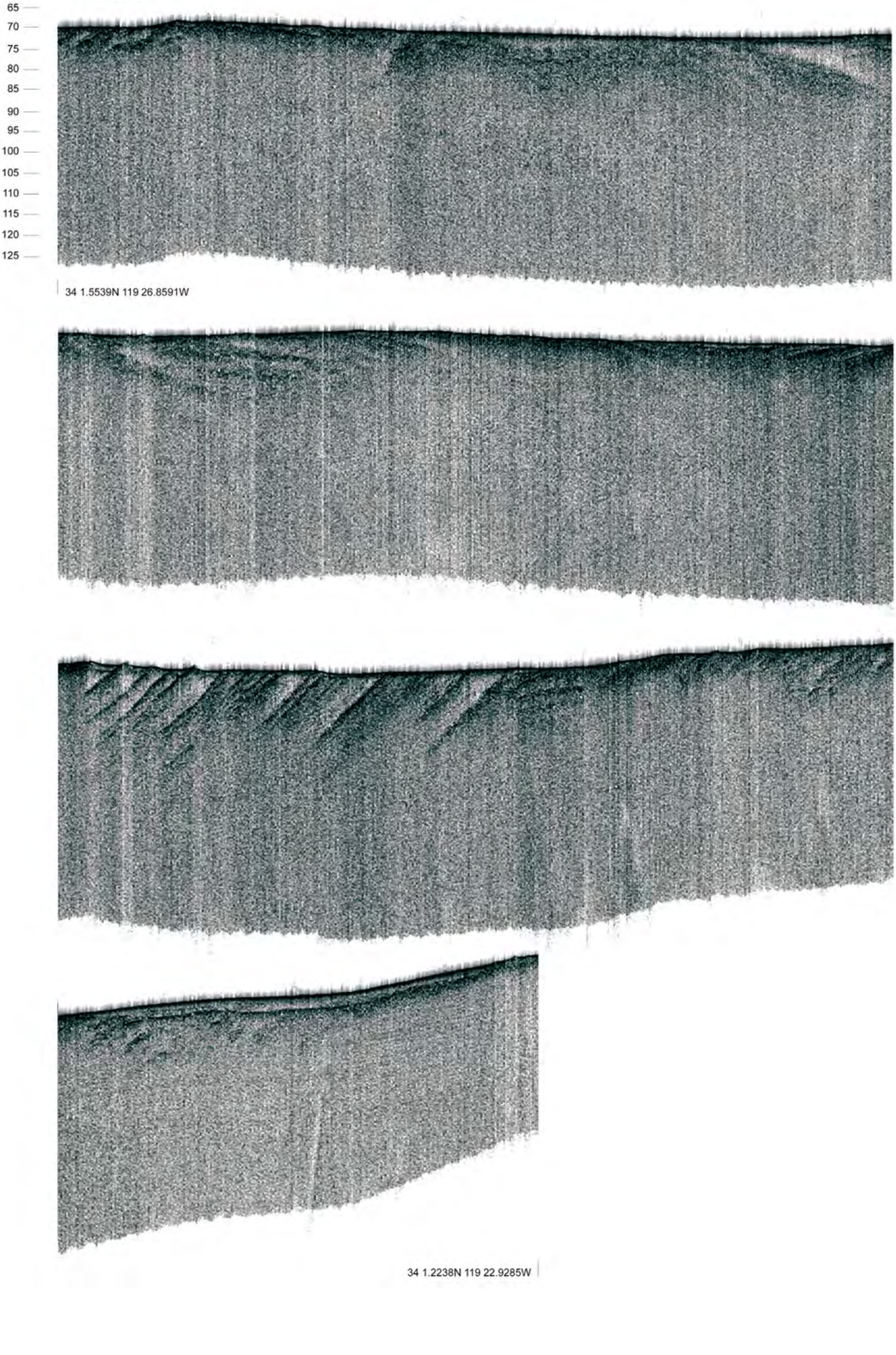

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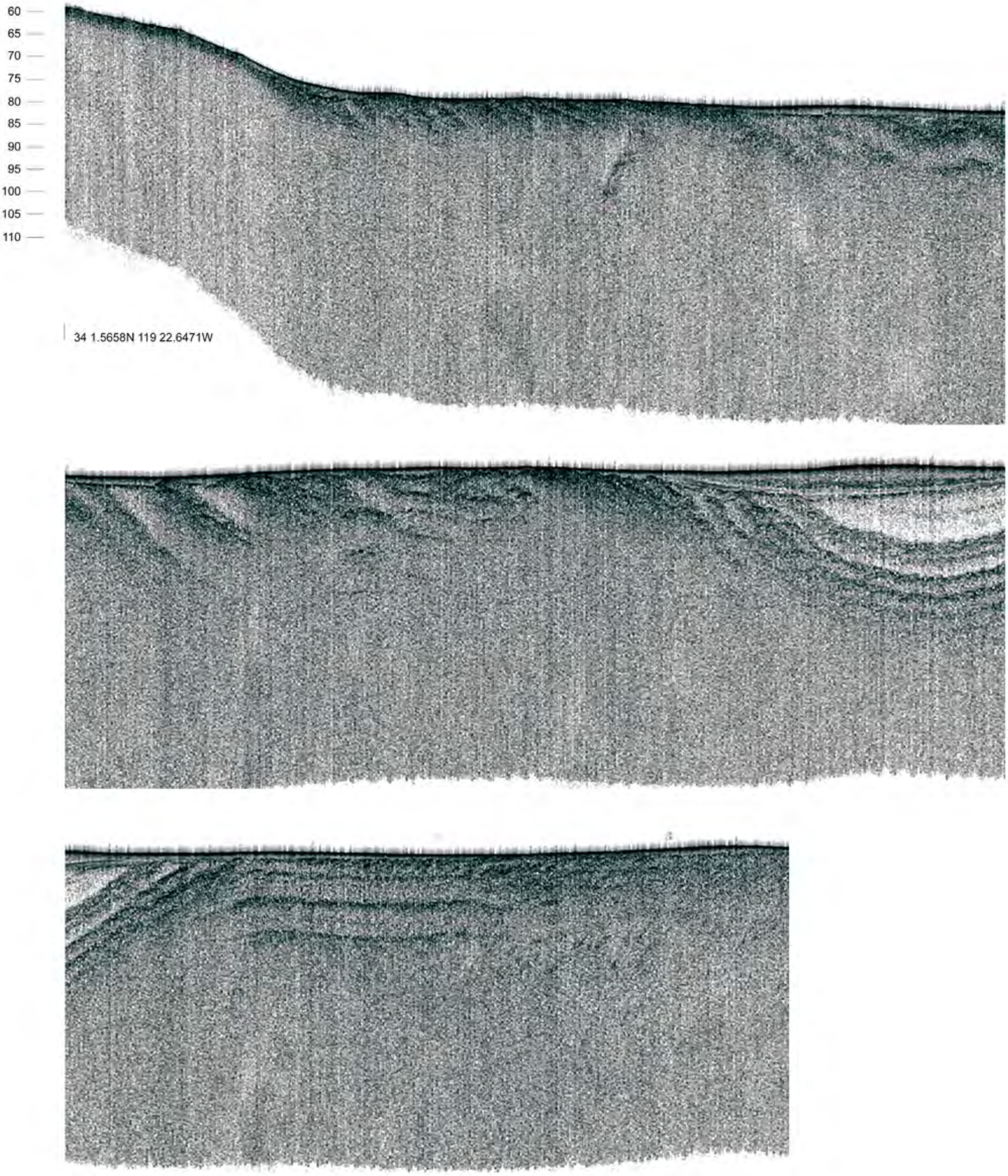

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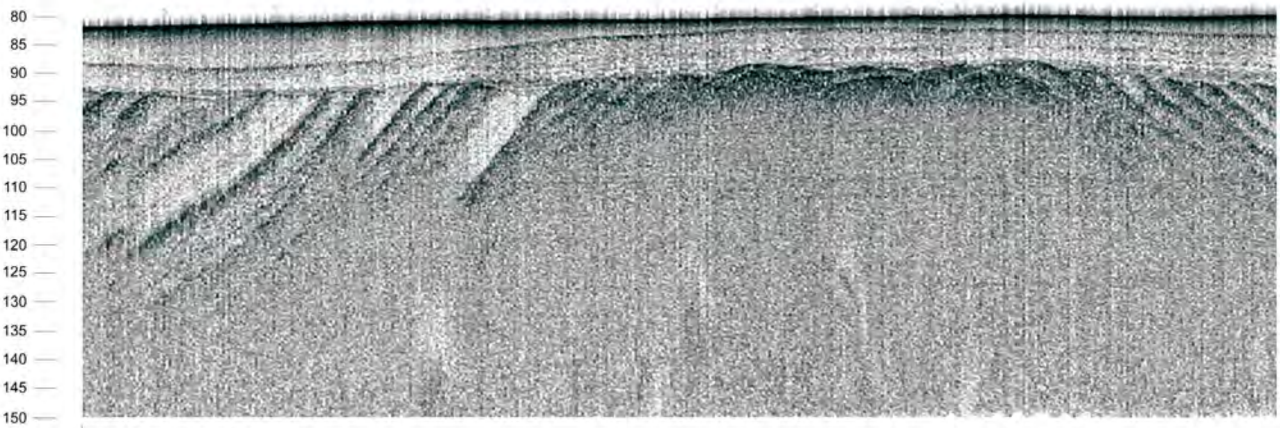

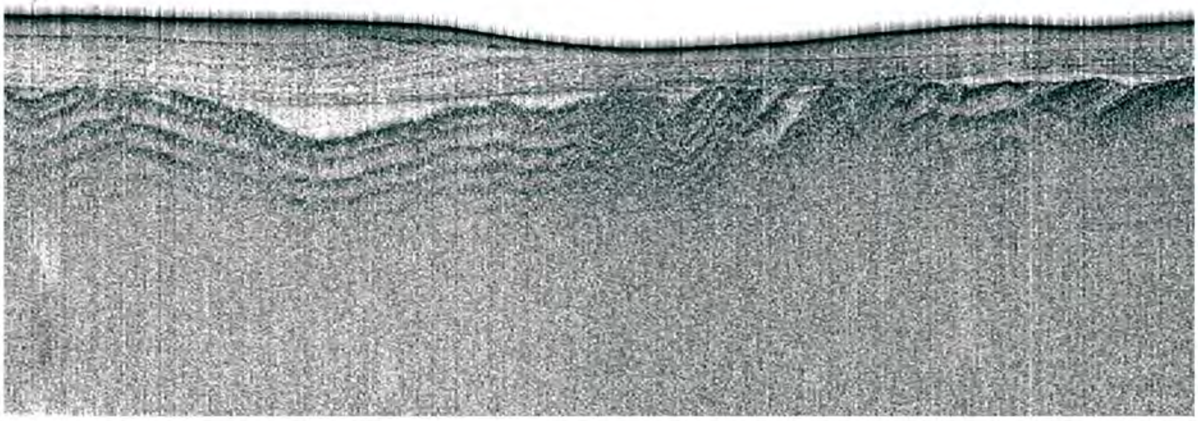

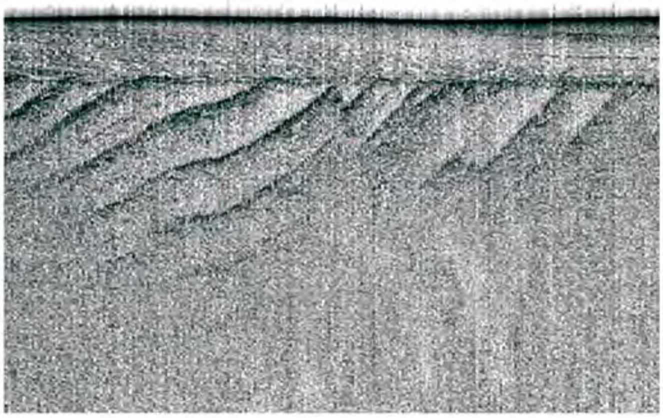

34 2.0150N 119 22.7548W

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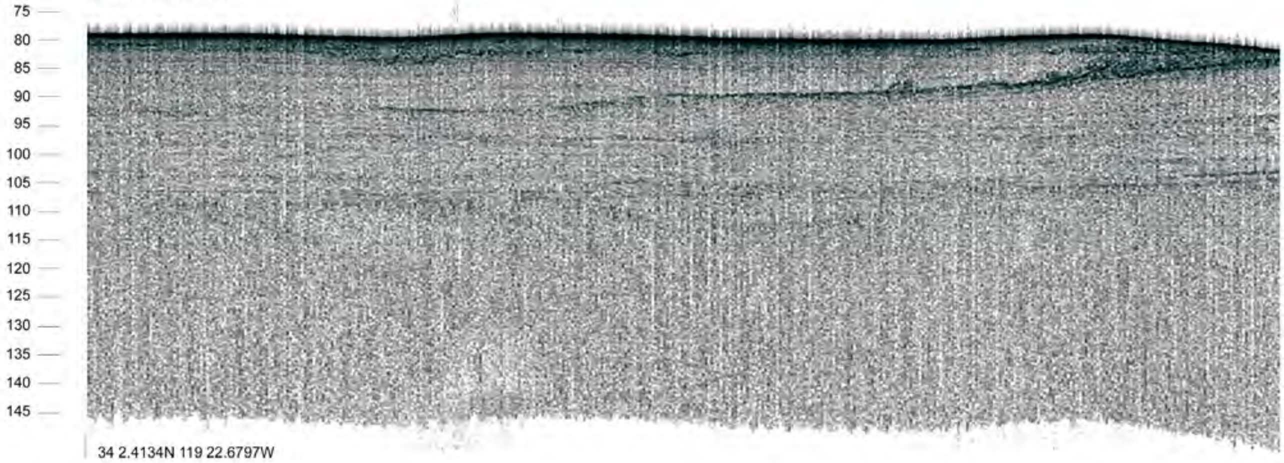
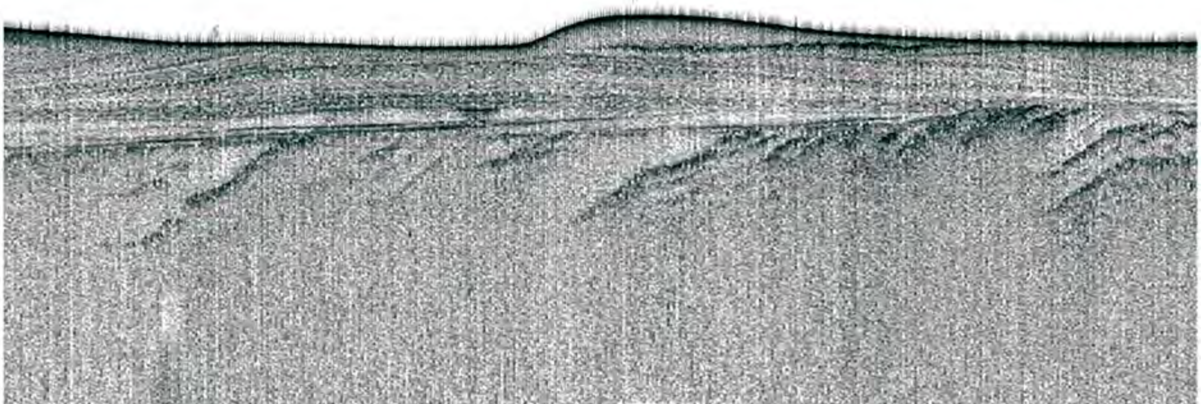
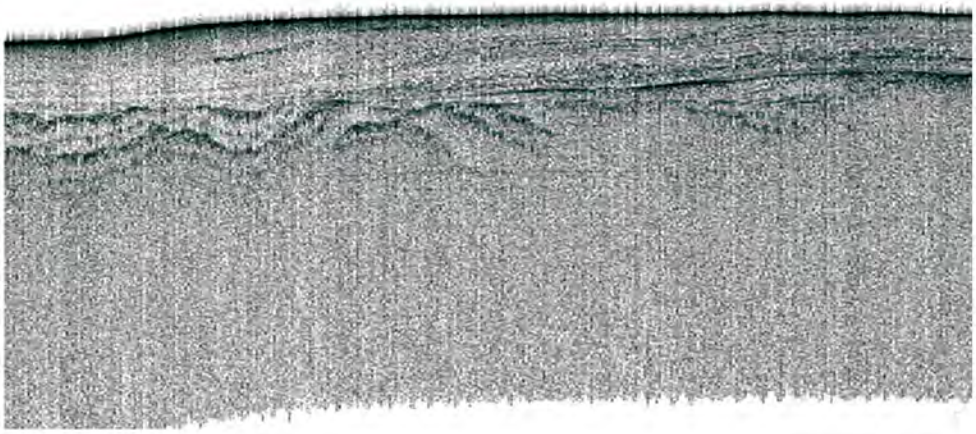


34 2.4134N 119 22.6797W





34 2.6828N 119 25.6169W

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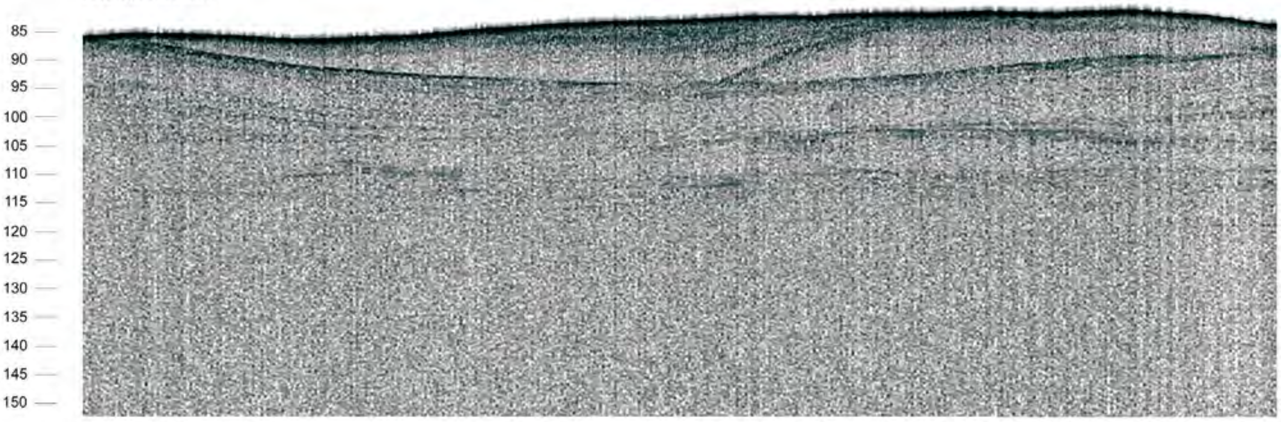

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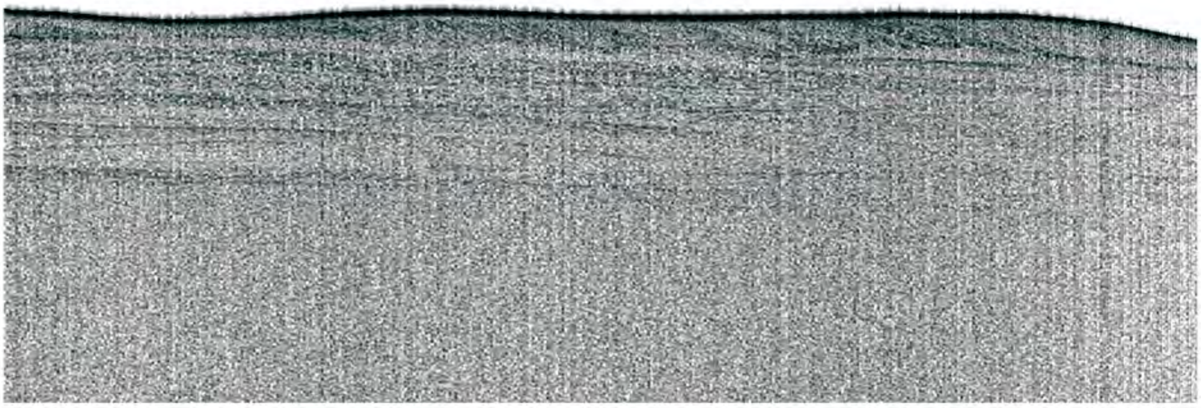

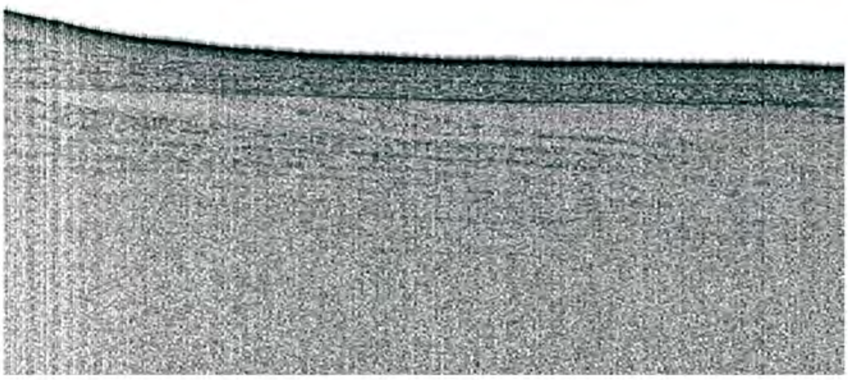

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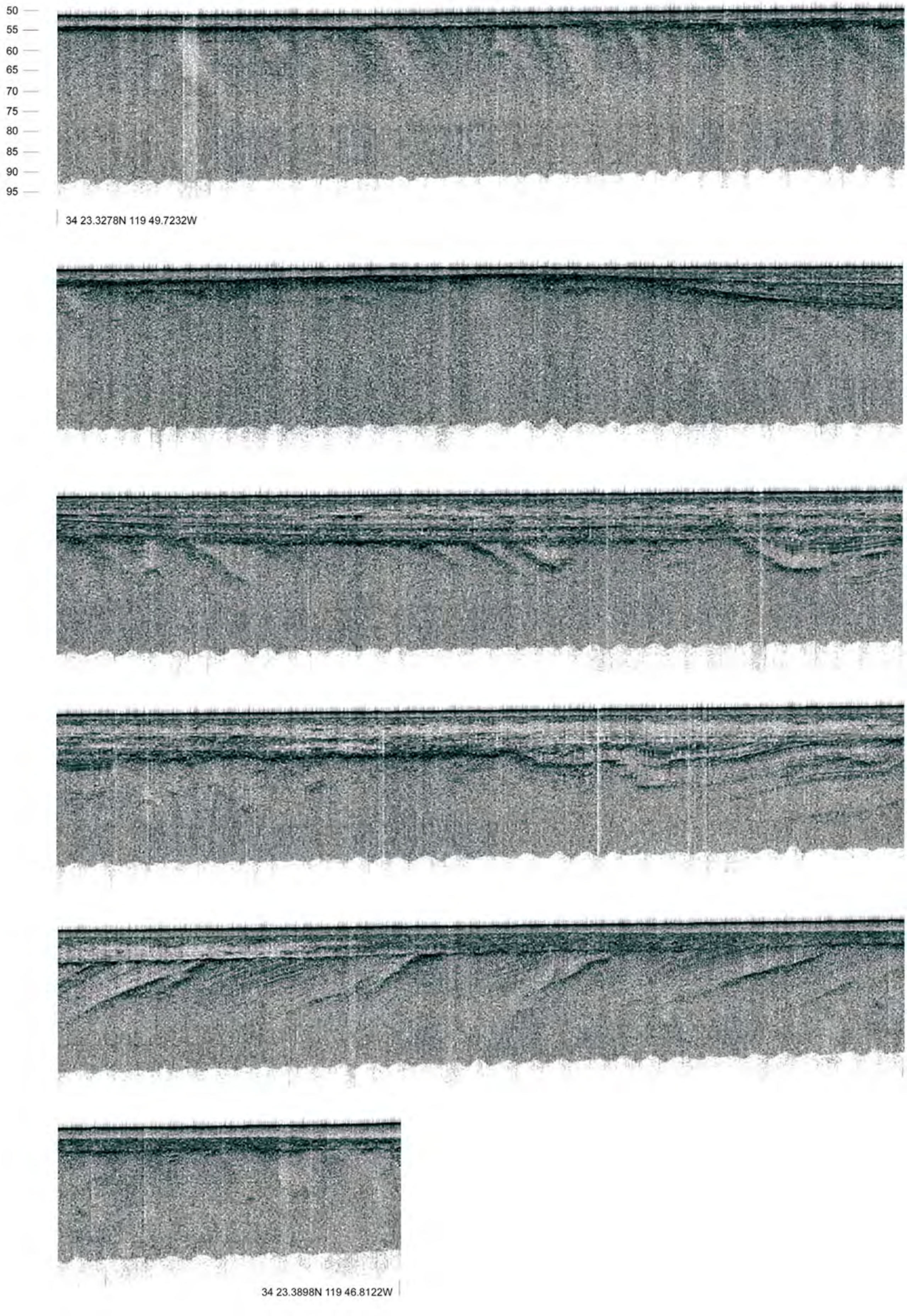
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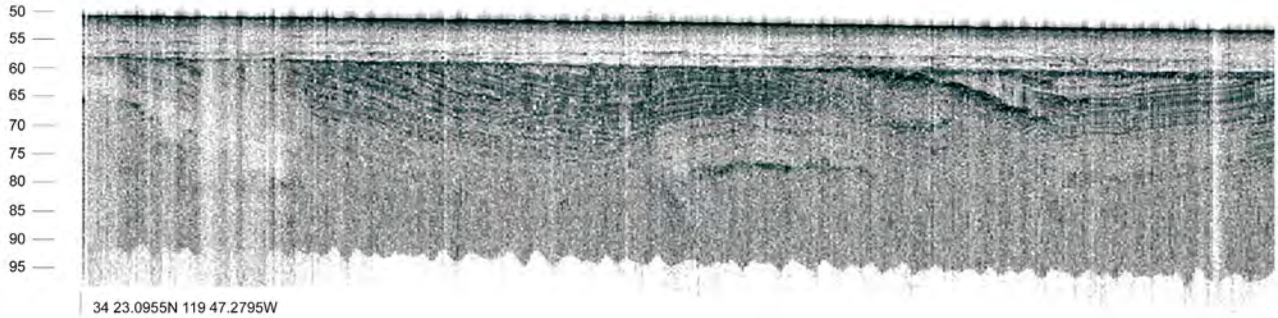
34 23.3278N 119 49.7232W
34 23.3898N 119 46.8122W

Goleta 2 :



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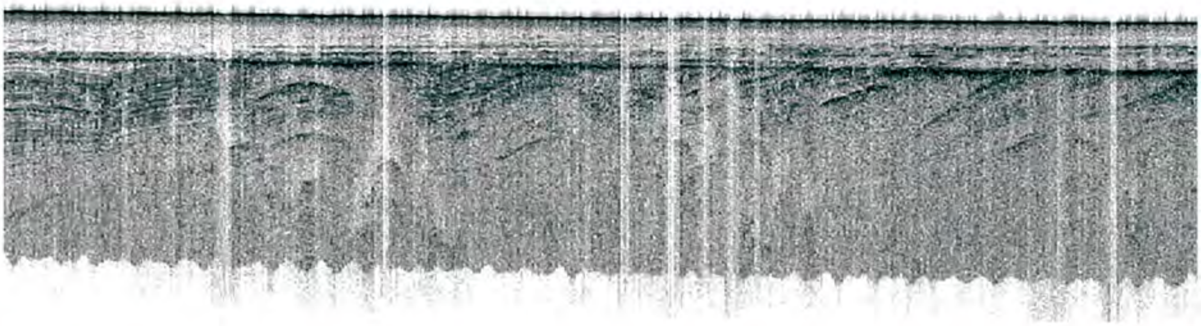

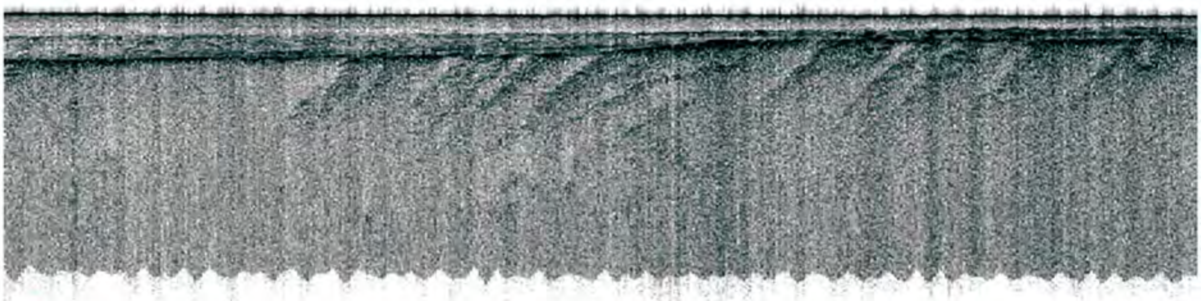

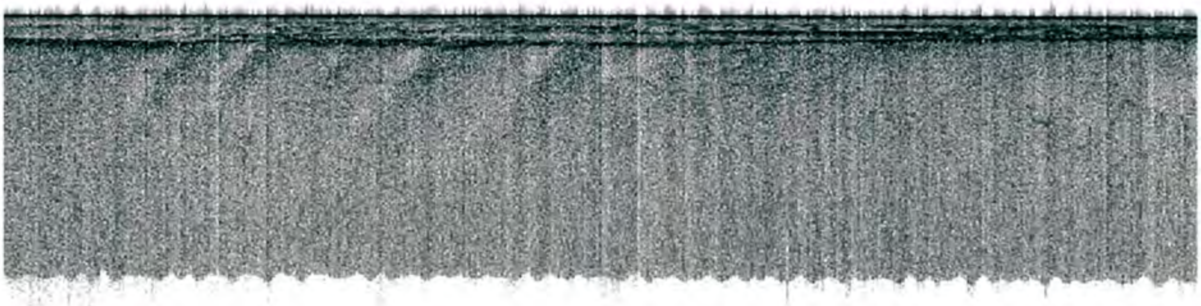

34 23.1403N 119 49.7977W

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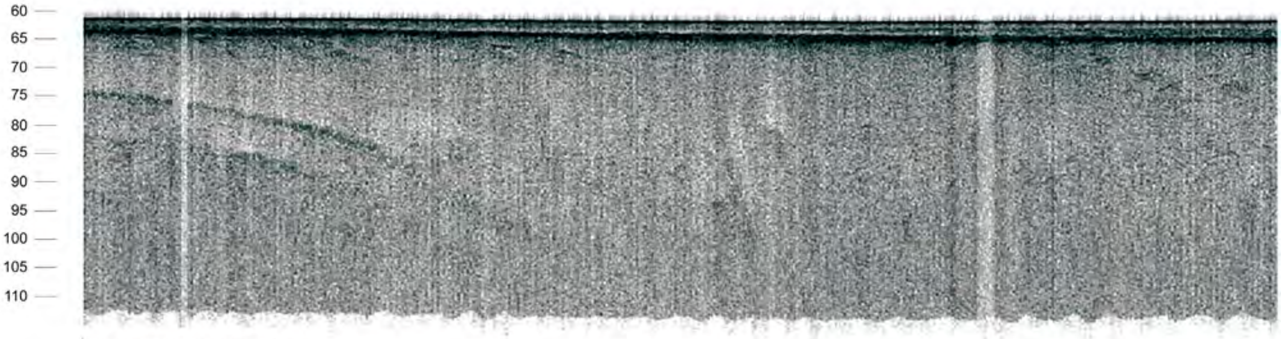

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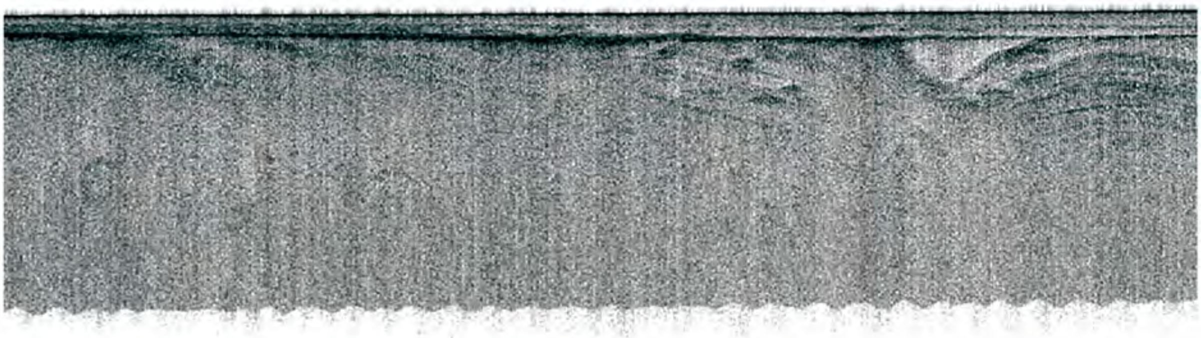

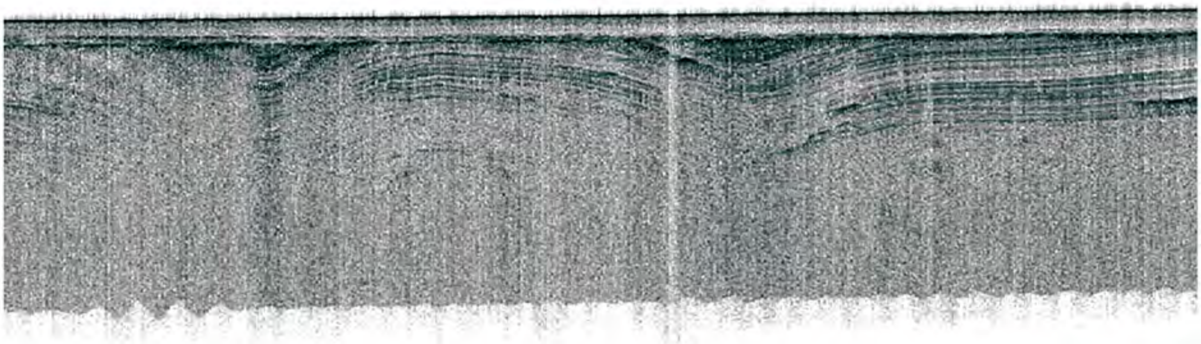

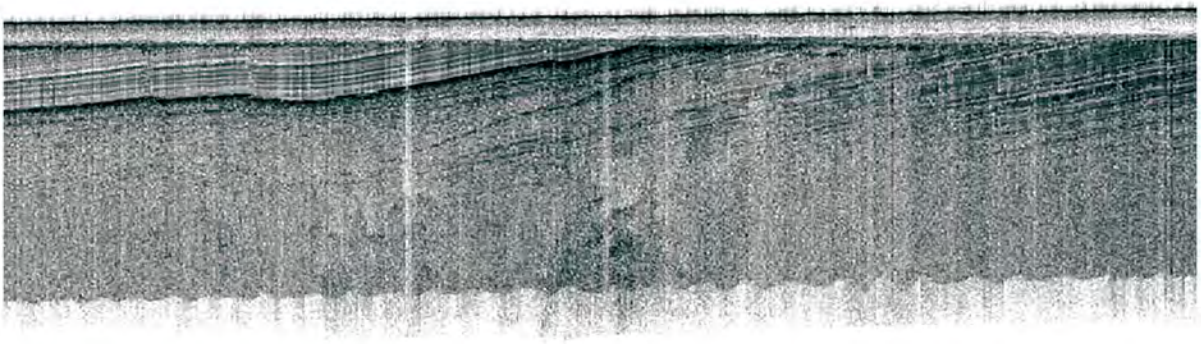

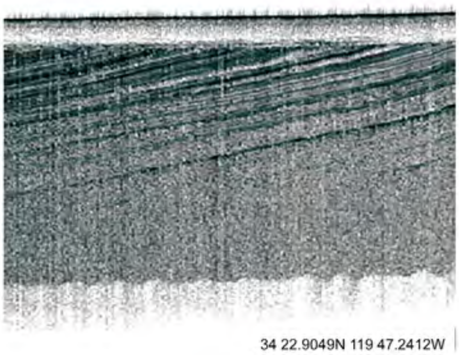

34 22.9049N 119 47.2412W

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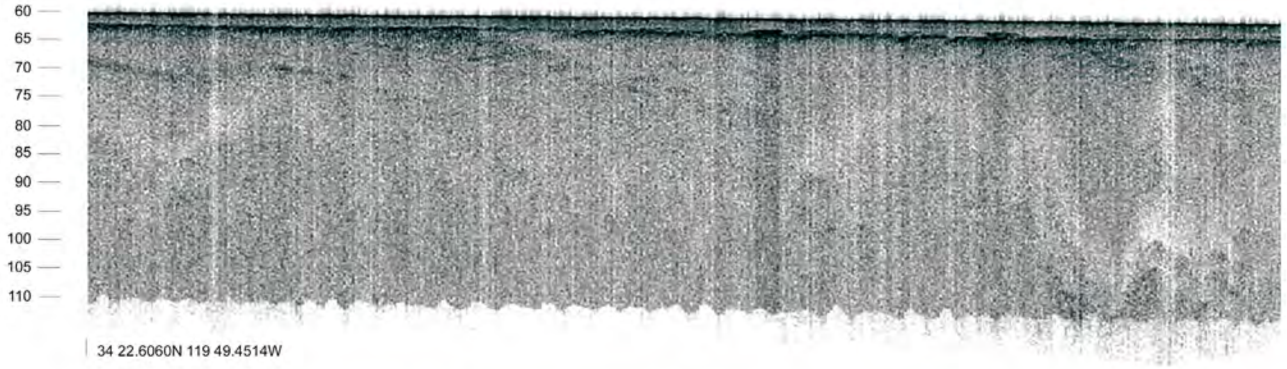
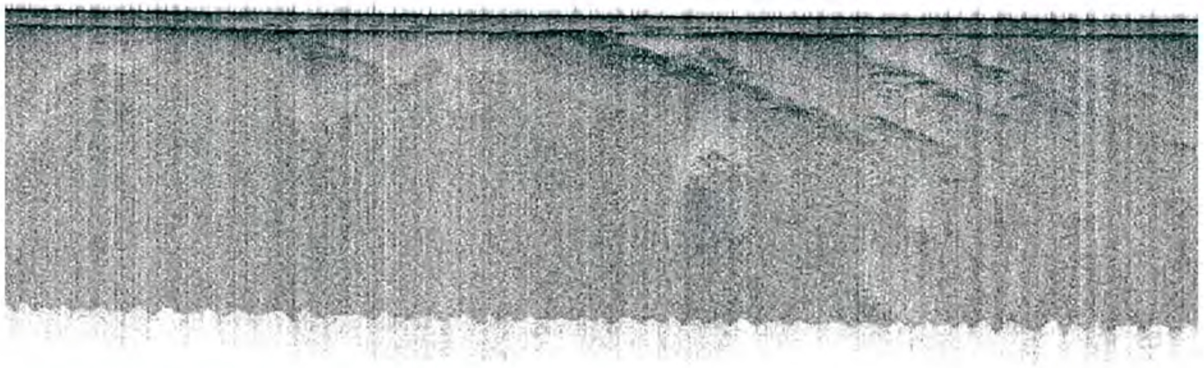
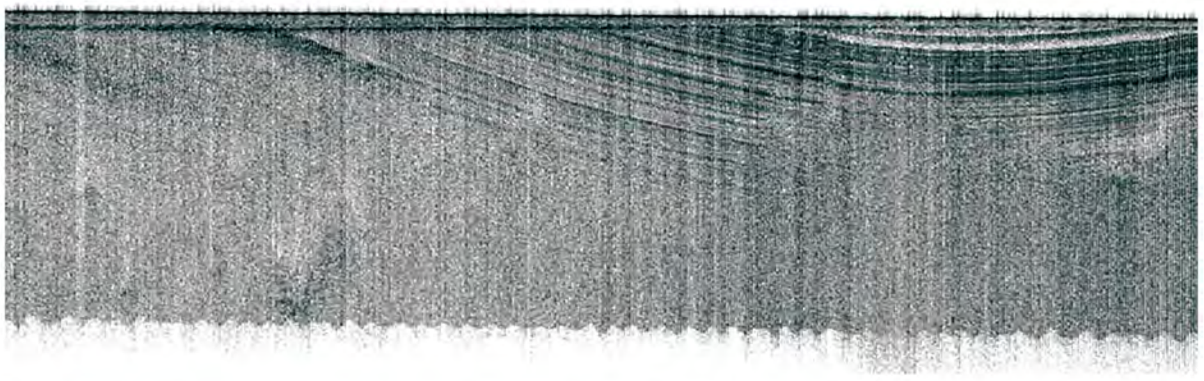
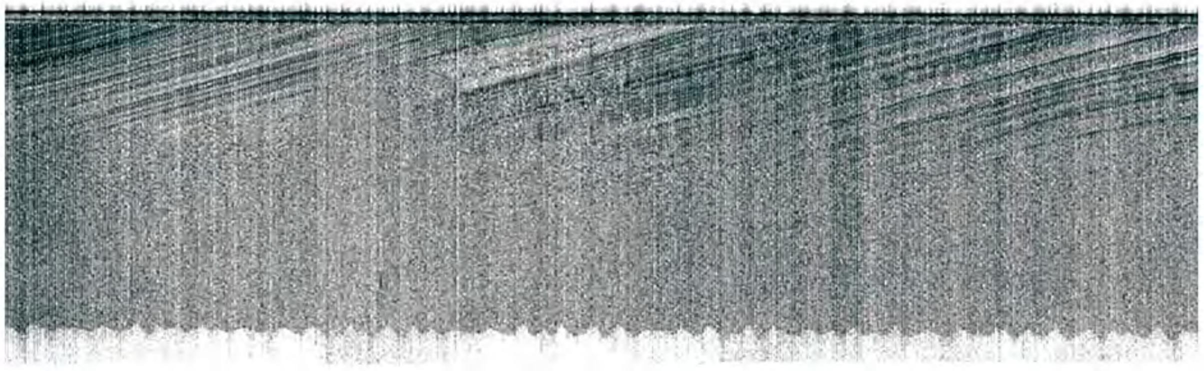
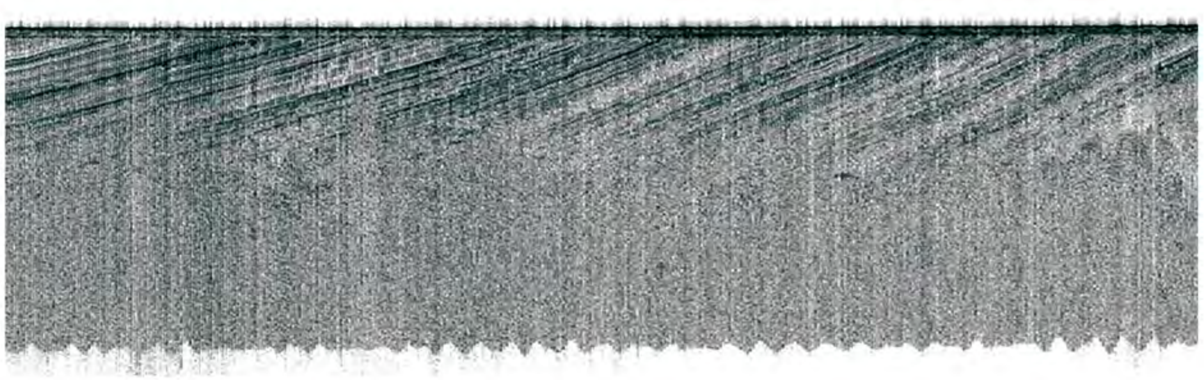


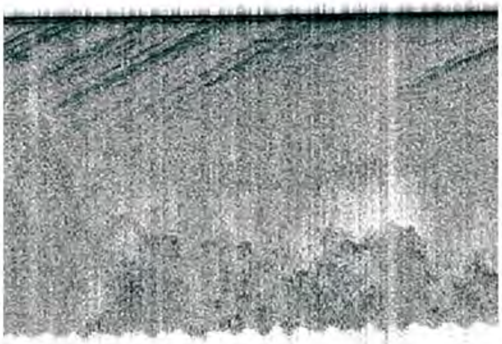
34 22.6060N 119 49.4514W











34 22.6080N 119 49.7750W

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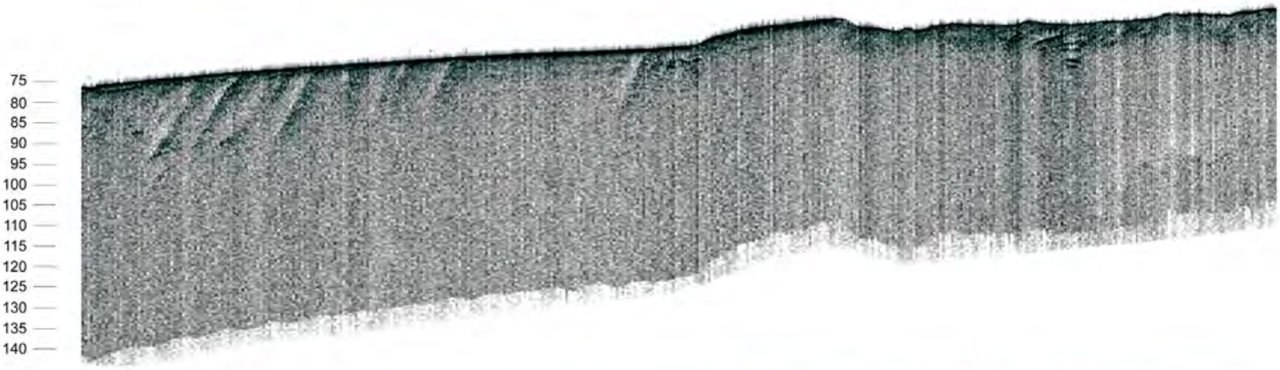
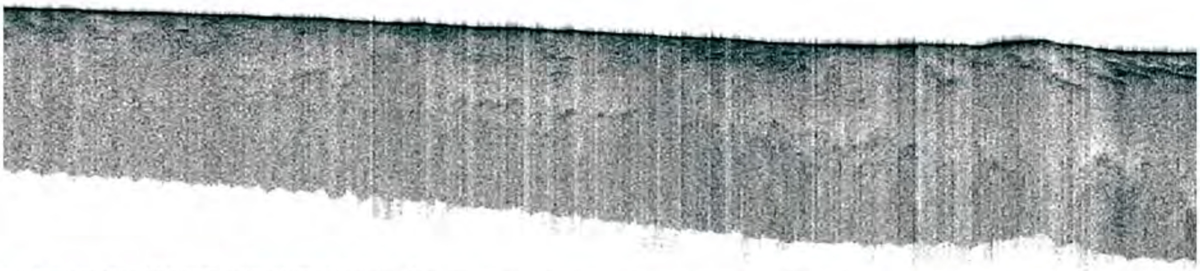
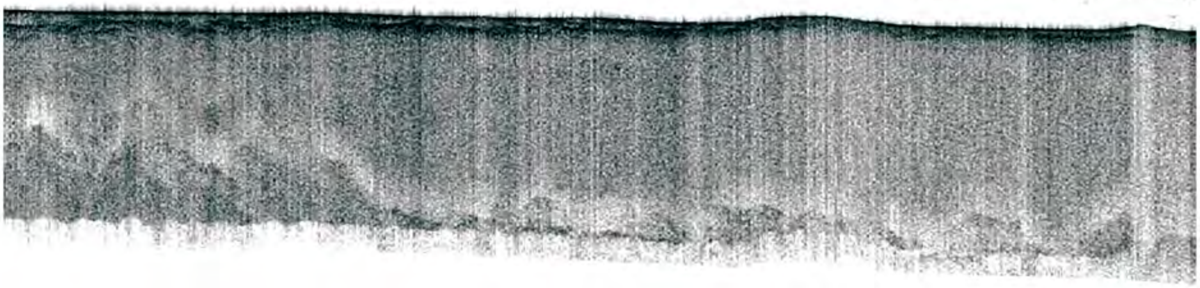
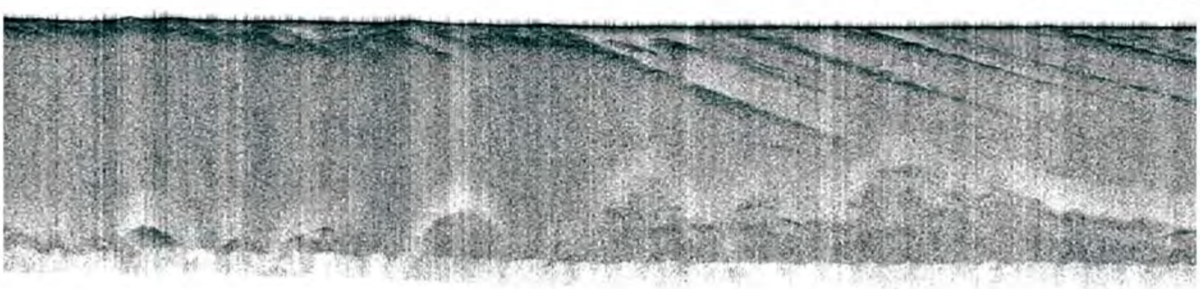
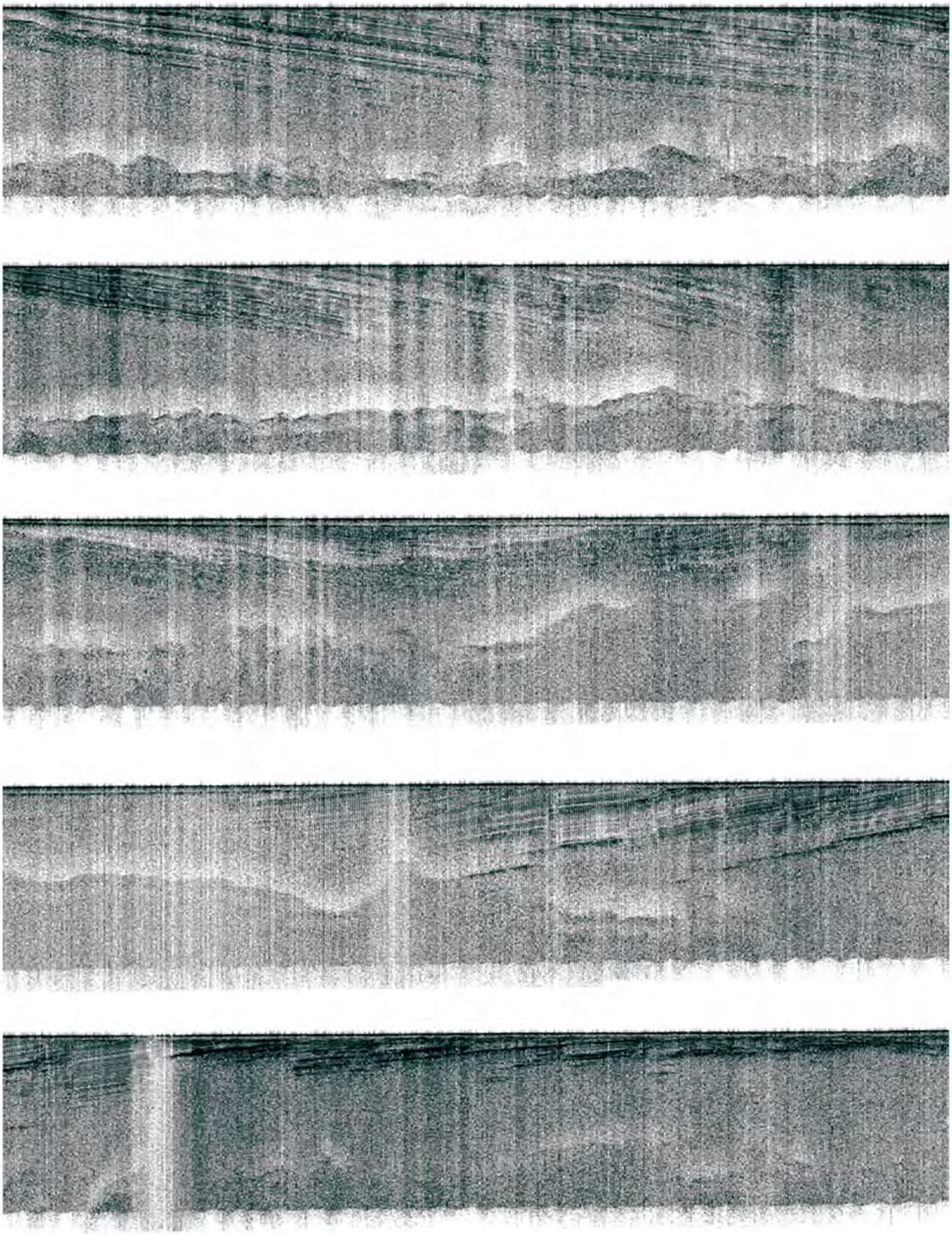


34 22.2224N 119 52.7019W







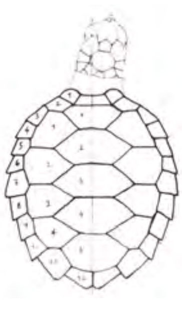


34 22.4109N 119 46.7935W

ABOUT THE ARTIST:
Alejandro Cano – Lasso Carretero (CATO) · doctorcato.com · doctorcato
Born 1988, Madrid, Spain.

Artist and early-career scientist with over ten years of experience in illustration and design. Committed to a multidisciplinar y approach to marine conservation, creates art to communicate scientific research and to inspire the general public to care for science and the ocean. Accomplished in various media, uses both hand-drawing and digital software to produce natural history plates, scientific figures or art installations. Works independently or in collaboration with other artists and scientists to communicate forefront oceanographic studies.

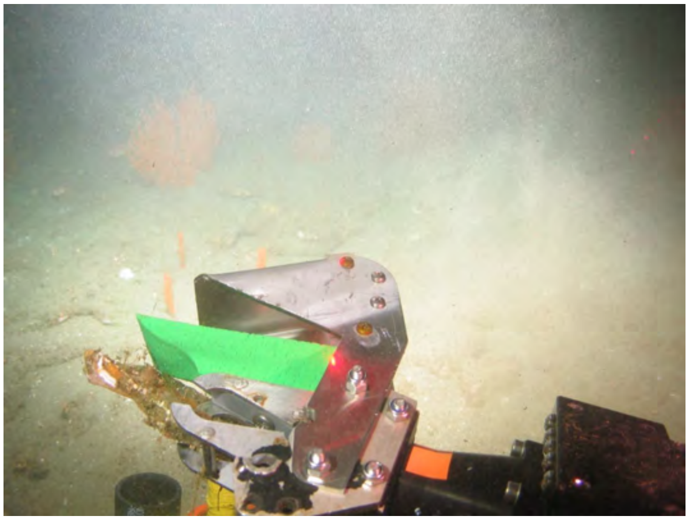
He is particularly interested in the adaptation of organisms to life in the ocean, and how their “conditions of existence” force them to become adapted in form and function. Based on this ecological principle, his designs are often inspired by forms found in nature, conditioned by the principles of space, light, color and transparency found in the architectural environment.



APPENDIX C

Sample Logs

SR2301_Anacapa_Rk1
Location: -119.414338156347 / 34.0233450405193
Description: Slate/shale sample collected near bedded outcrop during first ROV dive north of Anacapa Island. Sample shows bedding and breaks along planes.
Context: Sandy bottom. Abundant coral and fish in area.




Left: Video still of collection; Right: On shore image of sample.

SR2301_Anacapa_Rk2
Location: -119.43306748457 / 34.0489066921779
Description: Attempted to sample what appeared to be low relief carbonate on the seafloor on ROV dive 3 north of Anacapa Island. Sample was instead a collection of barnacle shells.
Context: Sandy bottom with low relief carbonate structures.


Left: Video still of collection; Right: On shore image of sample.

SR2301_Anacapa_Rk3

Location: -119.432996518319 / 34.0489316721013
Description: Following the collection of sample SR2301_Anacapa_Rk2, another sample was collected from what appeared to be low relief carbonate on the seafloor on ROV dive 3 north of Anacapa Island. Sample appears to be carbonate with abundant fauna attached and imbedded shells.
Context: Sandy bottom with low relief carbonate structures.

SR2301_Anacapa_Rk4

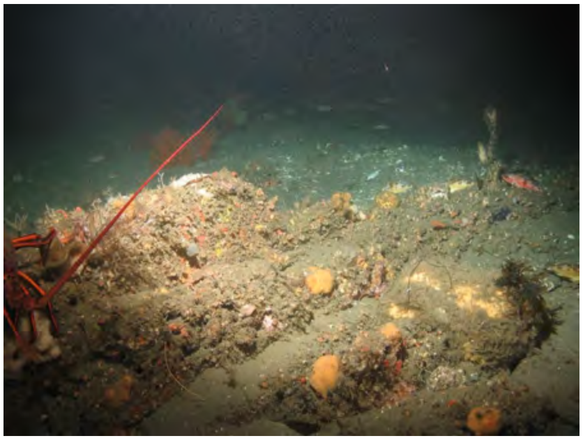
Location: -119.400734631088 / 34.019414134378
Description: Sample collected during ROV dive 7 north of Anacapa Island. Attempted sample was a piece of carbonate. Sample appears to be a predominately coral attached to carbonate.
Context: Sandy bottom with low relief carbonate structures.

Left: Video still of collection; Right: On shore image of sample.

Sample was returned to sea.

SR2301_Anacapa_Rk5

Location: -119.400460656862 / 34.0221156420832
Description: During ROV dive 7, the rocky substrate where abundant corals and fauna were seen was sampled. The sample is bedded and dark (possibly shale or slate) and does not appear to be carbonate.
Context: Sandy bottom with low relief carbonate structures with corals and fauna.



Left: Video still of collection; Right: On shore image of sample.

SR2301_Anacapa_Rk6

Location: -119.43295412736/ 34.0489481077194
Description: On ROV dive 8 north of Anacapa Island, carbonates were encountered both near to and coated with white bacterial mats. Sample SR2301_Anacapa_Rk6 was collected in an area without mats and appears to be predominately carbonate with a large (>10 cm) mussel attached.
Context: Sandy bottom with low relief carbonate structures with corals and fauna. Bacterial mats are present.

Left: Video still of collection; Right: On shore image of sample.

SR2301_Anacapa_Rk7

Location: -119.432138828433 / 34.0491208665682

Description: On ROV dive 8 north of Anacapa Island, carbonates were encountered both near and coated with white bacterial mats. Sample SR2301_Anacapa_Rk7 was collected in an area within several meters of bacterial mats and appears to be predominately carbonate.

Context: Sandy bottom with low relief carbonate structures with corals and fauna. Bacterial mats are present.

Left: Video still of collection; Right: On shore image of sample.

SR2301_Anacapa_Rk8

Location: -119.430184484901 / 34.0489119736885

Description: On ROV dive 8 north of Anacapa Island, carbonates were encountered both near and coated with white bacterial mats. Sample SR2301_Anacapa_Rk8 was collected in an area with several patchy bacterial mats. The sample appears to be predominately carbonate with faunal bore holes.

Context: Sandy bottom with low relief carbonate structures with corals and fauna. Bacterial mats are present.

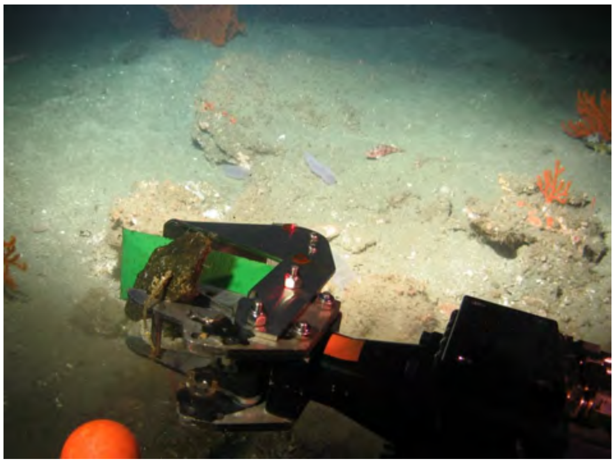
Left: Video still of collection; Right: On shore image of sample.

SR2301_Anacapa_Rk9

Location: -119.414473818186 / 34.0225696802228

Description: ROV Dive 10 targeted possible rock outcrops close to Anacapa Island. Sample SR2301_Anacapa_Rk9 targeted what appeared to be moderate/high relief outcrops. No bacterial mats were observed during this dive. The sample is not a carbonate, but is instead dark, dense, possibly metamorphic or volcanic, and does not have obvious layering/bedding.

Context: Sandy bottom with low relief carbonate structures with corals and fauna. Bacterial mats are present.



Left: Video still of collection; Right: On shore image of sample.

SR2301_Anacapa_Rk10

Location: -119.413344770312 / 34.0224859465692

Description: ROV Dive 10 targeted possible rock outcrops close to Anacapa Island. Sample SR2301_Anacapa_Rk10 targeted what appeared to be moderate/high relief outcrops. No bacterial mats were observed during this dive. The sample is dark, dense, possibly metamorphic or volcanic, and does not have obvious layering/bedding.

Context: Sandy bottom with low relief carbonate structures with corals and fauna.

Left: Video still of collection; Right: On shore image of sample.

SR2301_Anacapa_Rk11

Location: -119.412389668699 / 34.0234321074218
Description: ROV dive 11 targeted a series of high-relief, bedded, outcrops. Sample SR2301_Anacapa_Rk11 was near a low-dipping outcrop. The sample is not a carbonate, but is instead dark, dense, possibly metamorphic or volcanic, and does not have obvious layering/bedding.
Context: Sandy bottom with low relief carbonate structures with corals and fauna.

Left: Video still of collection; Right: On shore image of sample.

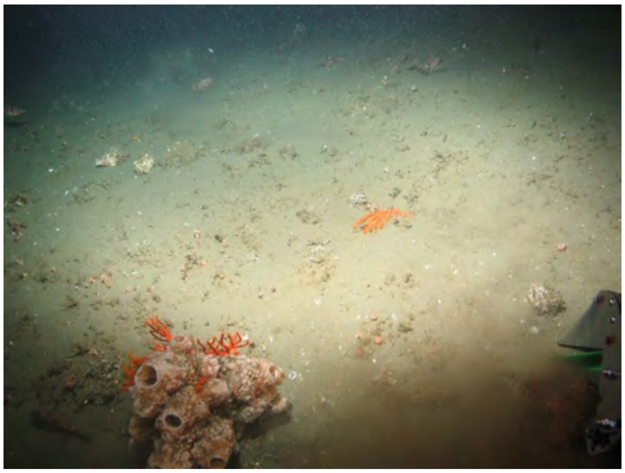
SR2301_Anacapa_Rk12

Location: -119.410297614988 / 34.0235938561094
Description: ROV dive 11 targeted a series of high-relief, bedded, outcrops. Sample SR2301_Anacapa_Rk12 was collected near a low-dipping outcrop that created a 1 to 2 meter high ledge in the seafloor. The sample is not a carbonate, but is instead dark, dense, possibly metamorphic or volcanic, and does not have obvious layering/bedding.
Context: Sandy bottom with low relief carbonate structures with corals and fauna.

Left: Video still of collection; Right: On shore image of sample.

SR2301_Anacapa_Rk13

Location: -119.399275848615/ 34.022381087251
Description: ROV dive 11 targeted a series of high-relief, bedded, outcrops. Sample SR2301_Anacapa_Rk13 was collected in a flat area of the seafloor with limited outcrops.
Context: Sandy bottom with low relief carbonate structures with corals and fauna.



Left: Video still of collection; Right: On shore image of sample.

SR2301_Anacapa_Rk14

Location: -119.422481044725 / 34.044782471129
Description: Sample SR2301_Anacapa_Rk14, was collected during ROV dive 13 within a local bathymetric low within a kilometer of the pockmarks explored in dive 3. The bathymetric low contained abundant biomaterial (appearing to be both terrestrial and marine in origin), possibly deposited during the recent and ongoing (at the time) storm. The sample appears to be a large empty calcareous tube of a Vermetidae. Tubeworms of this size are commonly found near active cold seeps.
Context: Sandy bottom with scattered urchin, empty calcareous Vermetidae tubes, broken shells, and shell hash.

Left: Video still of collection; Right: On shore image of sample.

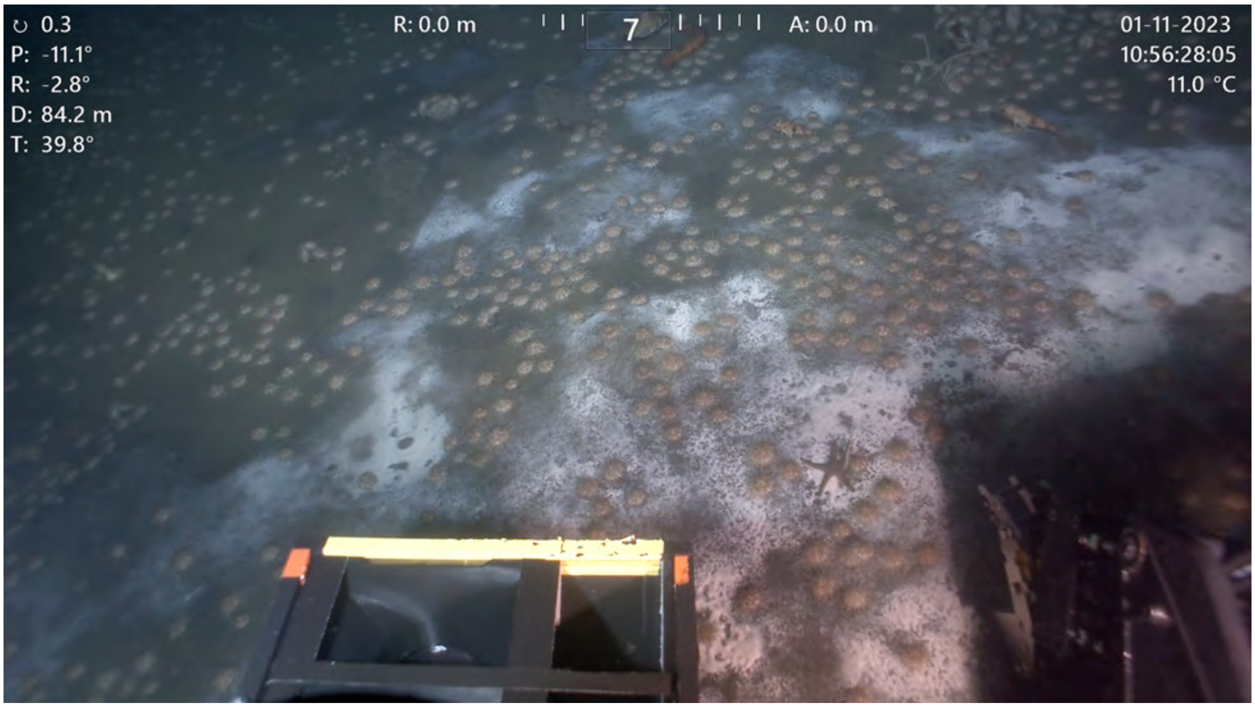
Sample was returned to the sea.

SR2301_Anacapa_Sd1

Location: -119.422407400327 / 34.0446992443972
Description: Sediment sample
Context: SR2301_Anacapa_Sd1, was collected during ROV dive 12 where pockmarks were noted in the bathymetry. Here, the seafloor was predominately sandy with abundant sea urchins and dark patches of the seafloor. Some of the darker stained seafloor were collocated with white and grey bacterial mats. The sediment sample was taken from a dark patch of the seafloor. The sample gave off a sulfur-like odor once aboard.

SR2301_Anacapa_Sd2

Location: -119.42244077848 / 34.044769608312
Description: Sediment sample
Context: SR2301_Anacapa_Sd2, was collected during ROV dive 13 where pockmarks were noted in the bathymetry. Here, the seafloor was predominately sand with abundant sea urchins and dark patches of the seafloor. Some of the darker stained seafloor were collocated with white and grey bacterial mats. Compared to Dive 12, this area had more abundant urchins and bacterial mats. The sediment sample was taken from a bacterial mat and the dark stained sediment below.



SR2301_Anacapa_Sd3

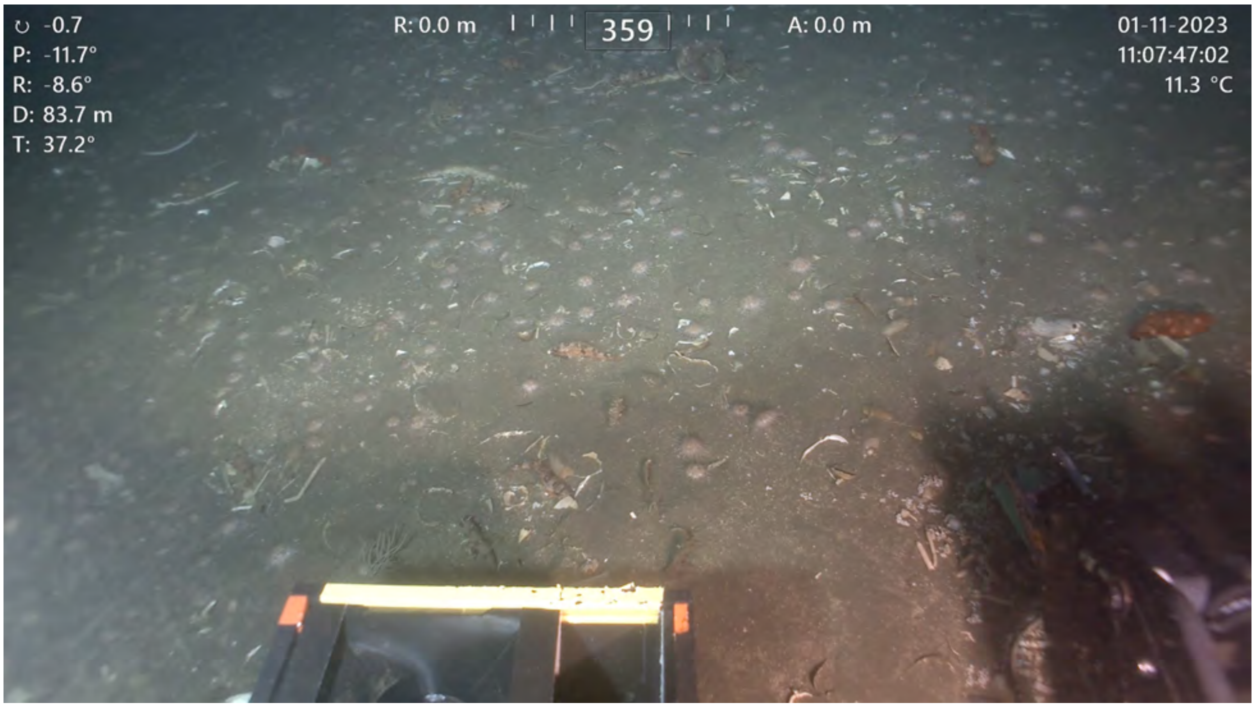
Location: -119.422331125332 / 34.0447147747538

Description: Sediment sample

Context: SR2301_Anacapa_Sd3, was collected during ROV dive 13 where pockmarks were noted in the bathymetry. Here, the seafloor was predominately sand with abundant sea urchins and dark patches of the seafloor. Some of the darker stained seafloor were collocated with white and grey bacterial mats. Compared to Dive 12, this area had more abundant urchins and bacterial mats. The sediment sample was taken from a bacterial mat and the dark stained sediment below. This sample contains bacterial mats, apparent from the white 'hair-like' structures observed in the sample ashore.

SR2301_Anacapa_Sd4

Location: -119.422318985614 / 34.0447629041696
Description: Sediment sample
Context: SR2301_Anacapa_Sd4, was collected during ROV dive 13 where pockmarks were noted in the bathymetry. Within a bathymetric low, shell hash was noted. Sample SR2301_Anacapa_Sd4 collected darkened seafloor sediment with abundant shell hash.



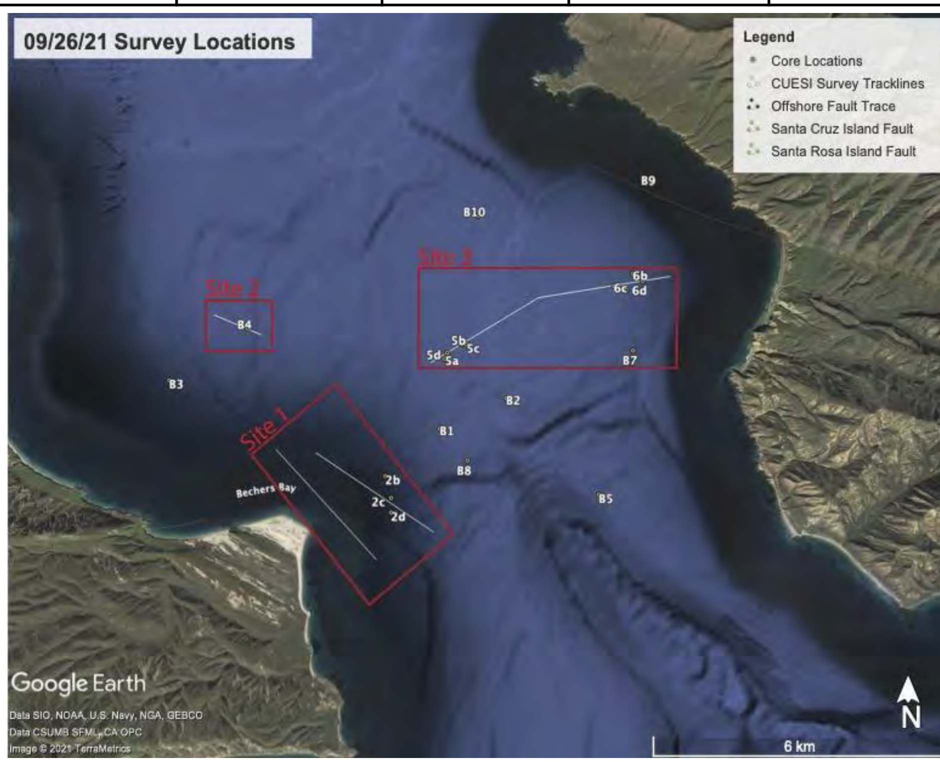
APPENDIX D

Survey Logs

CSEM SURVEY LOGS

Survey Area: SCP

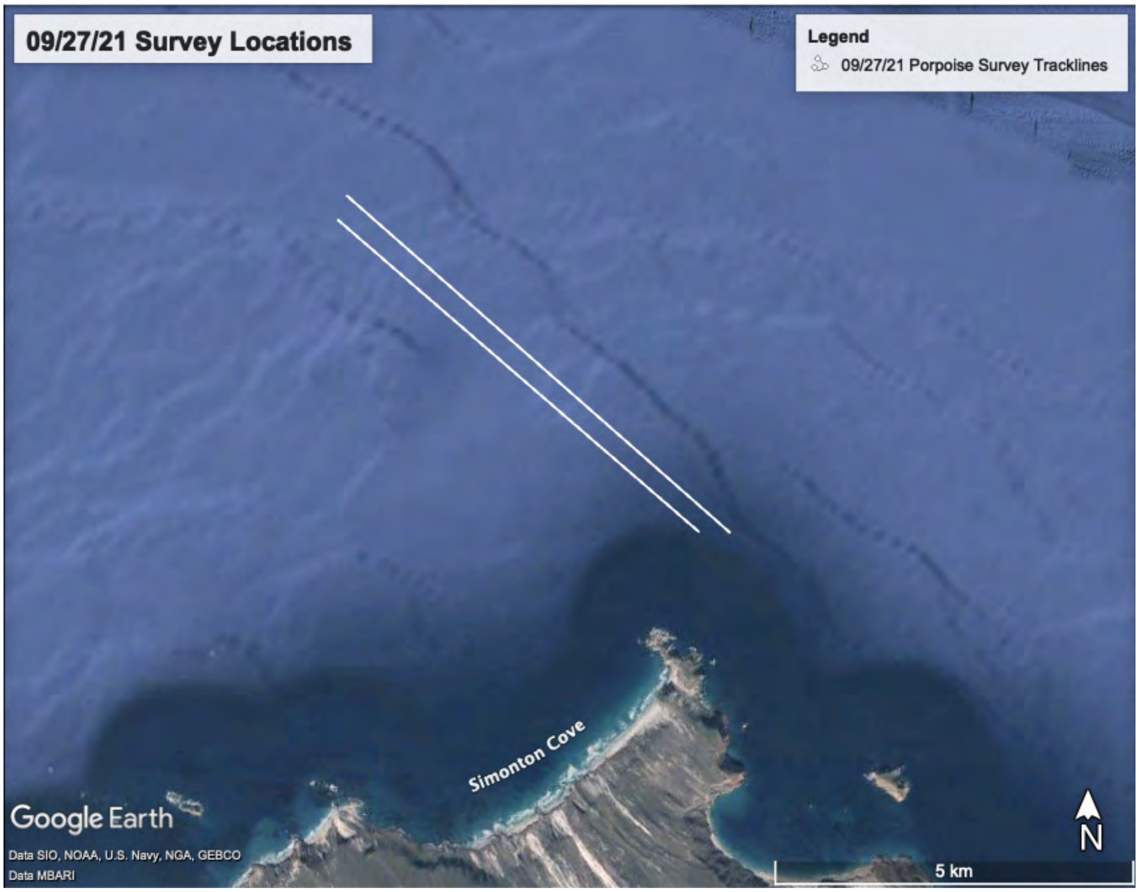
Site	Survey Line Name	Start Lat. (DD)	Start Lon. (DD)	End Lat. (DD)	End Lon. (DD)	Length (km)
1	CUESI_092621_L1	33.976089°	-119.963633°	33.995084°	-119.985243°	2.92
1	CUESI_092621_L2	33.994707°	-119.976740°	33.980817°	-119.951200°	2.81
2	CUESI_092621_L3	34.018664°	-119.998754°	34.015043°	-119.988362°	1.0
3	CUESI_092621_L4	34.010419°	-119.951853°	34.021606°	-119.928425°	2.51
3	CUESI_092621_L5	34.021606°	-119.928425°	34.025226°	-119.900086°	2.64



Survey location for CUESI survey on 09/26/21. CUESI_092621_L1 was previously surveyed using the porpoise array in 2019; the results from this cruise indicate possible fluid flow along the fault trace. This CUESI survey targeted possible seepage along a fault trace and several core locations. The CUESI array was deployed and recovered in each site location.

Survey Area: SMI

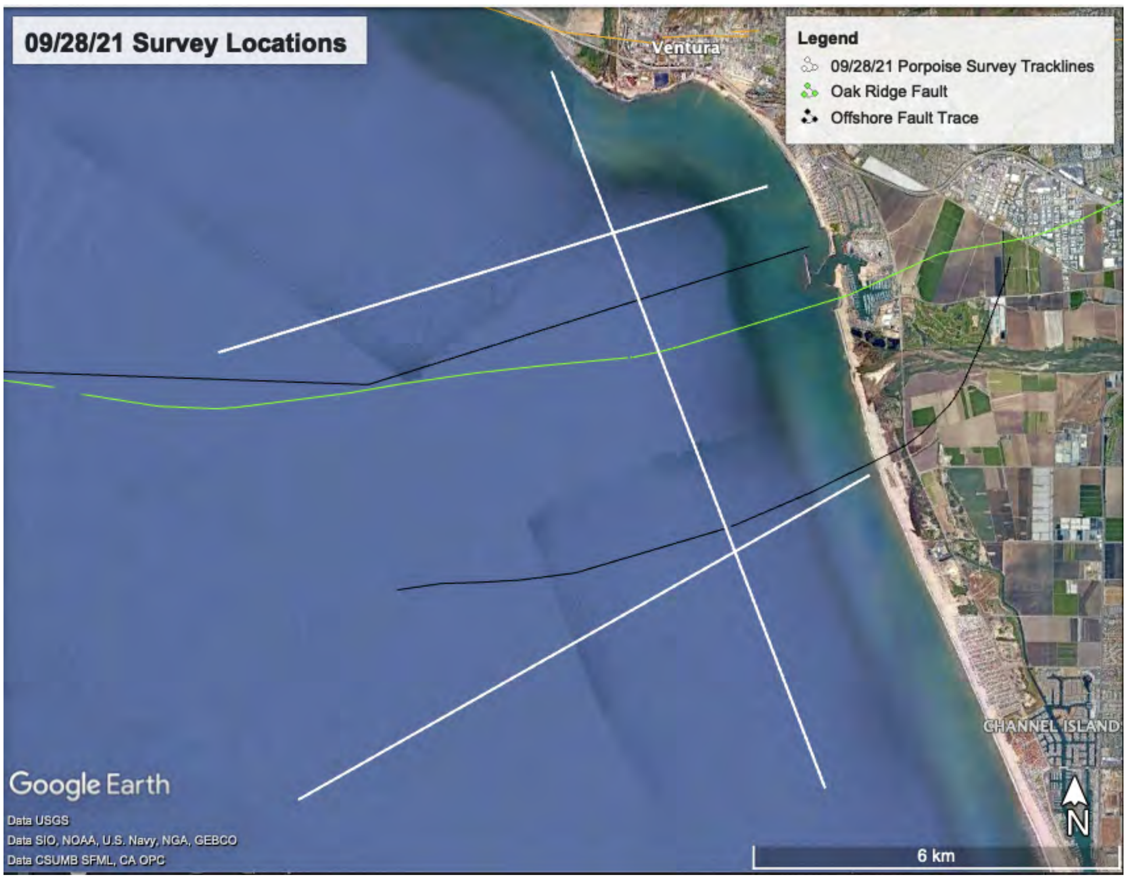
Survey Line Name	Start Lat. (DD)	Start Lon. (DD)	End Lat. (DD)	End Lon. (DD)	Length (km)
NOAA_S1_092721_L1	34.126423°	-120.416276°	34.088357°	-120.362354°	6.50
NOAA_S1_092721_L2	34.088155°	-120.357751°	34.129166°	-120.414828°	6.95



Map of CSEM survey lines collected on 09/27/21. Line 1 is the western line and was surveyed from north to south. Line 2 is the eastern line and was surveyed from south to north

Survey Area: Ventura

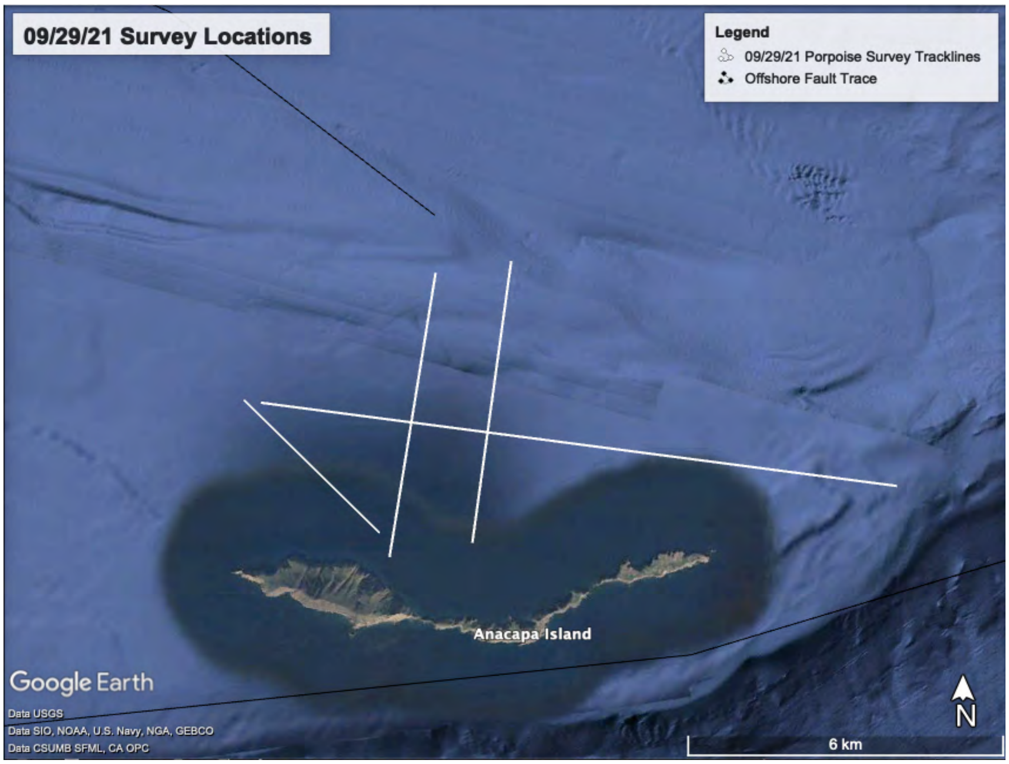
Survey Line Name	Start Lat. (DD)	Start Lon. (DD)	End Lat. (DD)	End Lon. (DD)	Length (km)
NOAA_S1_092821_L1	34.171142°	-119.363256°	34.218322°	-119.262234°	10.7
NOAA_S1_092821_L2	34.172854°	-119.270251°	34.277161°	-119.318400°	12.4
NOAA_S1_092821_L3	34.260525°	-119.280348°	34.236142°	-119.376976°	9.35



Map of CSEM survey lines collected on 09/28/21. The survey was designed to test the influence of faulting on the coastal aquifer supplying freshwater to the communities of Ventura and Oxnard.

Survey Area: ANA

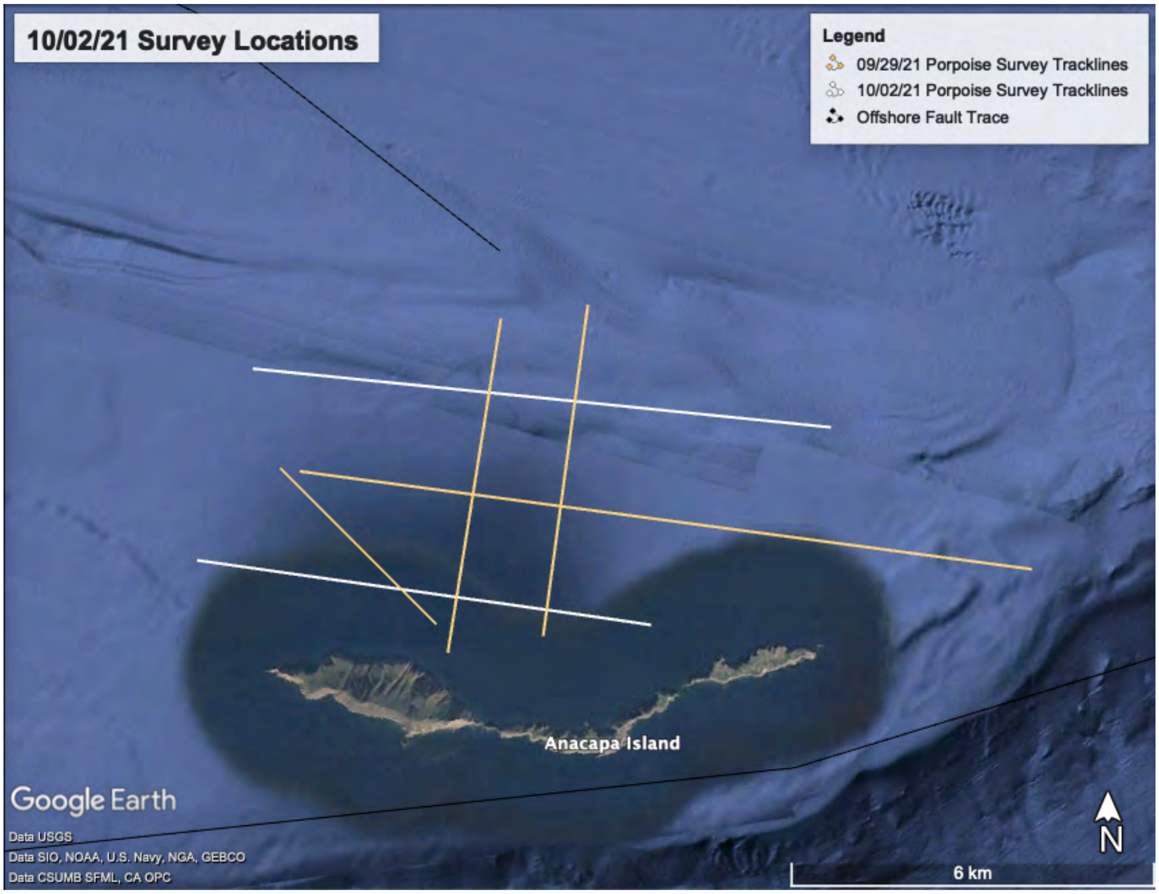
Survey Line Name	Start Lat. (DD)	Start Lon. (DD)	End Lat. (DD)	End Lon. (DD)	Length (km)
NOAA_S1_092921_L1	34.018475°	-119.400662°	34.061676°	-119.393582°	4.86
NOAA_S1_092921_L2	34.059995°	-119.407321°	34.016200°	-119.415850°	4.92
NOAA_S1_092921_L3	34.019772°	-119.417476°	34.040312°	-119.442111°	3.22
NOAA_S1_092921_L4	34.039866°	-119.438996°	34.027004°	-119.323253°	10.8



Map of CSEM survey lines collected 09/29/2021. This location offshore Anacapa Island has hydrocarbon slicks and stringers in the water column inferring the presence of a hydrocarbon seep.

Survey Area: ANA

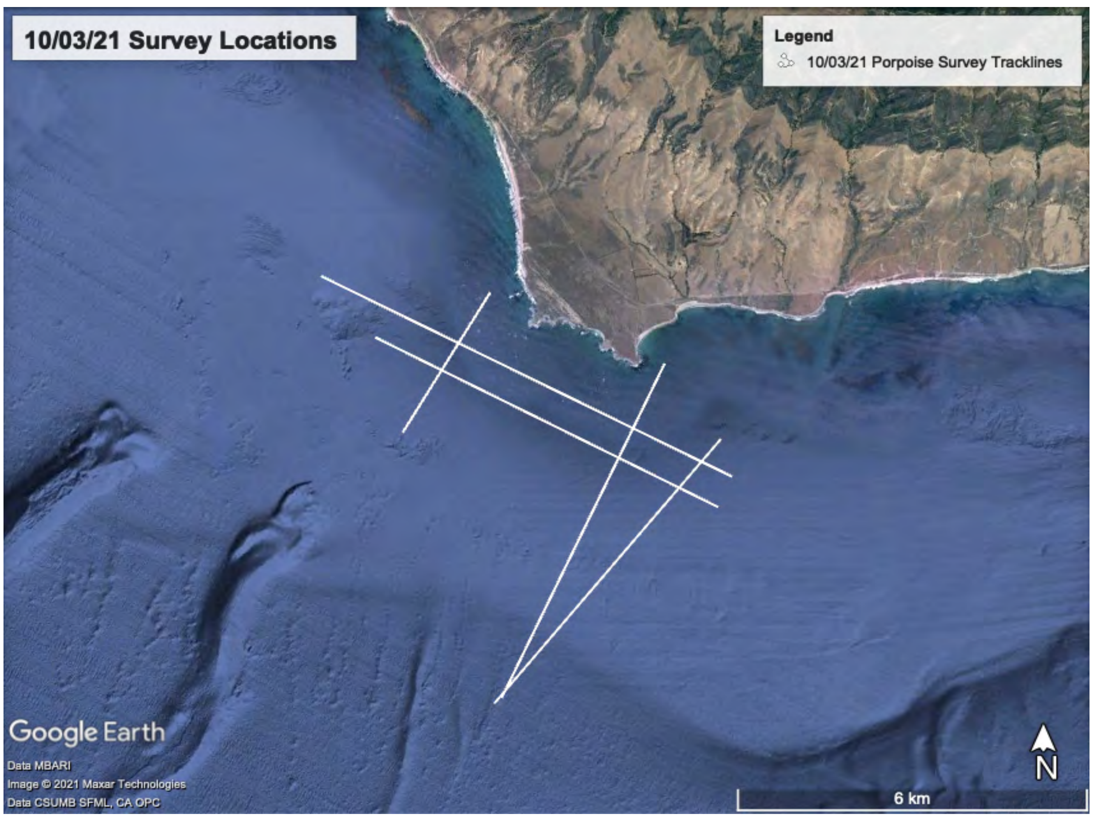
Survey Line Name	Start Lat. (DD)	Start Lon. (DD)	End Lat. (DD)	End Lon. (DD)	Length (km)
NOAA_S2_100221_L1	34.045624°	-119.355170°	34.053170°	-119.445927°	8.62
NOAA_S2_100221_L2	34.028138°	-119.455080°	34.019613°	-119.383302°	6.78



White lines are CSEM survey lines collected on 10/02/2021.

Survey Area: PtC

Survey Line Name	Start Lat. (DD)	Start Lon. (DD)	End Lat. (DD)	End Lon. (DD)	Length (km)
NOAA_S2_100321_L1	34.455913°	-120.509476°	34.425134°	-120.435321°	7.61
NOAA_S2_100321_L2	34.430850°	-120.437465°	34.390696°	-120.478206°	5.86
NOAA_S2_100321_L3	34.391339°	-120.476929°	34.442389°	-120.447610°	6.31
NOAA_S2_100321_L4	34.420521°	-120.437993°	34.446652°	-120.500114°	6.37
NOAA_S2_100321_L5	34.453563°	-120.478942°	34.431907°	-120.494802°	2.79

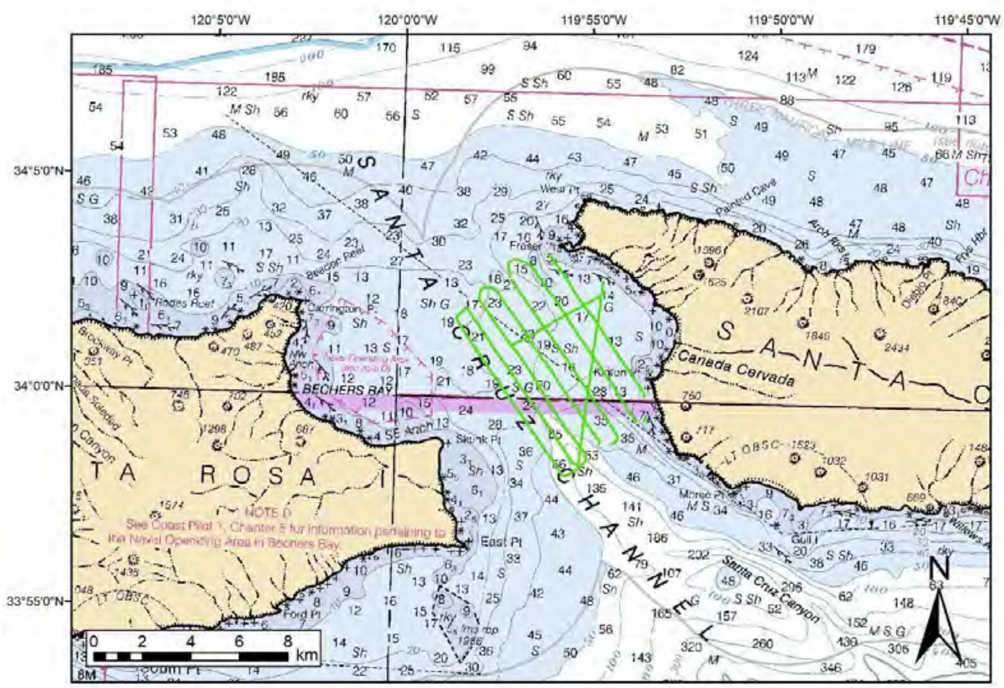


Map of survey lines collected on 10/03/21 offshore Point Conception. This survey is designed to map the geology and hydrocarbon migration systems below the previously mapped asphalt volcanoes in this region. Additionally, these lines expand on a previously mapped area to target pockmarks on the seafloor possibly related to methane seepage.

SUBBOTTOM SURVEY LOGS

Survey Area: SCP

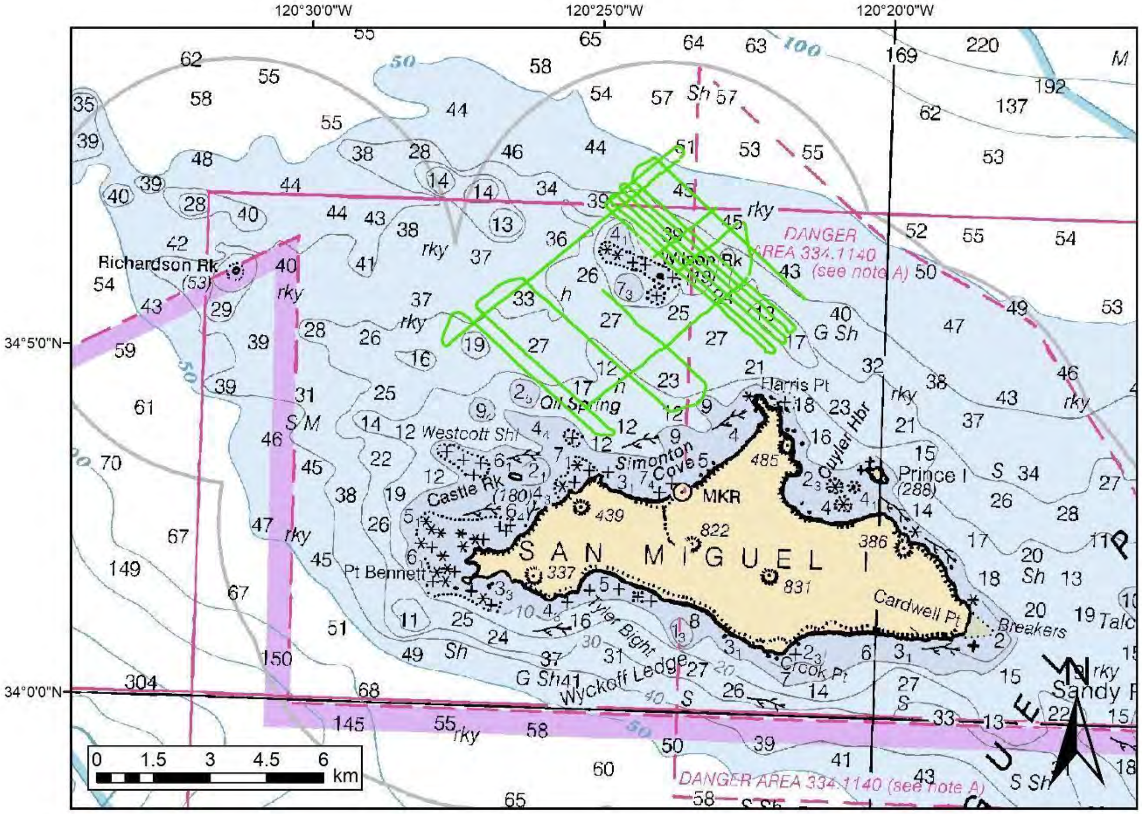
Line	Area	Start		End		Length (km)
CI_Mar22_L01	SR-SC Channel	-119.9336510	34.0558060	-119.9318930	34.0543800	0.29
CI_Mar22_L02	SR-SC Channel	-119.9318520	34.0543380	-119.8968510	34.0121660	5.82
CI_Mar22_L02.001	SR-SC Channel	-119.8971190	34.0125370	-119.8892250	34.0021730	1.42
CI_Mar22_L03	SR-SC Channel	-119.8927080	33.9920900	-119.9406900	34.0505640	8.09
CI_Mar22_L04	SR-SC Channel	-119.9502030	34.0456990	-119.9010250	33.9867530	8.13
CI_Mar22_L05	SR-SC Channel	-119.9087730	33.9832740	-119.9571450	34.0418800	8.20
CI_Mar22_L06	SR-SC Channel	-119.9640540	34.0375530	-119.9150630	33.9793660	8.04
CI_Mar22_L07.002	SR-SC Channel	-119.9207190	33.9754010	-119.9693600	34.0345930	8.16
CI_Mar22_L08	SR-SC Channel	-119.9737060	34.0294540	-119.9251630	33.9708800	8.05
CI_Mar22_L09	SR-SC Channel	-119.9179040	33.9744790	-119.9091960	34.0459860	8.14
CI_Mar22_L10	SR-SC Channel	-119.9084640	34.0415790	-119.9496660	34.0203210	4.55



Santa Cruz Passage study area transects shown in green, collected 7 March 2022.

Survey Area: SMI

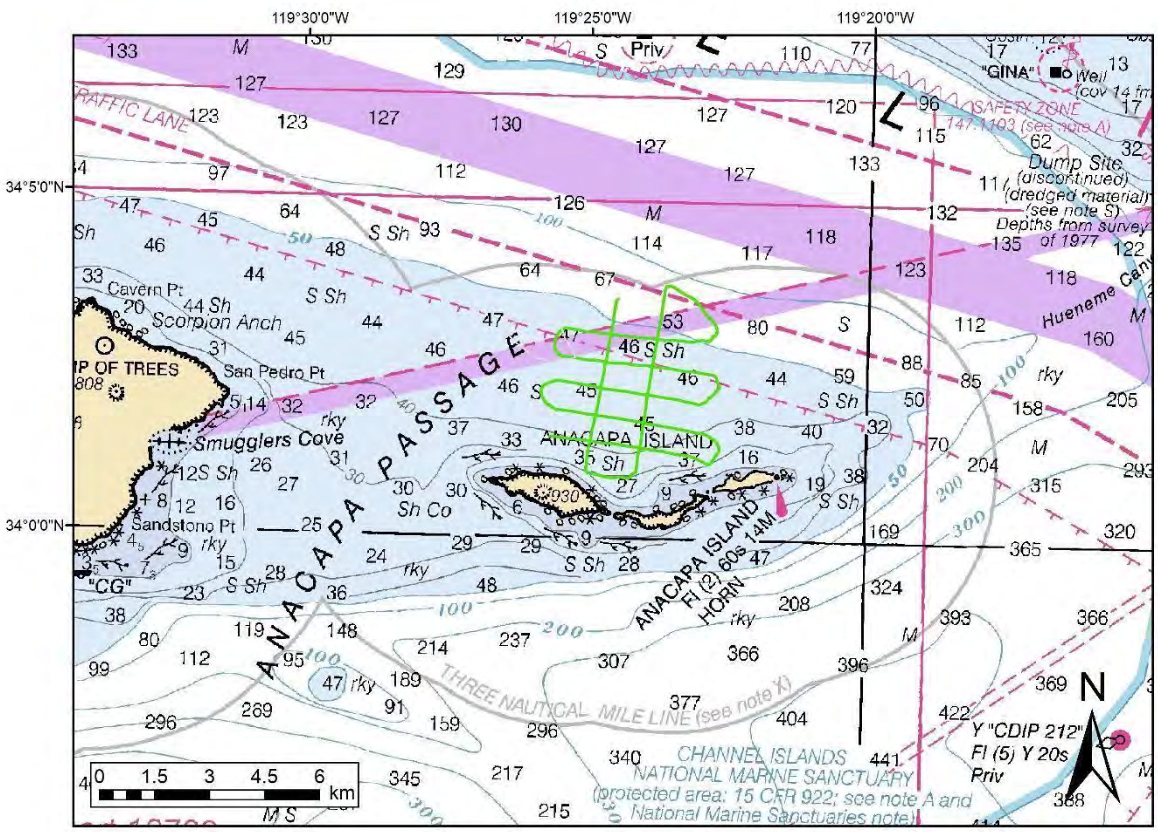
Line	Area	Start		End		Length (km)
CI_Mar22_L 11	San Miguel	-120.3563720	34.0996930	-120.3999100	34.1317420	5.49
CI_Mar22_L 12	San Miguel	-120.4065430	34.1262110	-120.3596270	34.0934590	5.71
CI_Mar22_L 13	San Miguel	-120.3616780	34.0925760	-120.4079750	34.1251340	5.71
CI_Mar22_L 14	San Miguel	-120.4087890	34.1233720	-120.3623700	34.0908890	5.65
CI_Mar22_L 15	San Miguel	-120.3641190	34.0898820	-120.4113440	34.1229330	5.81
CI_Mar22_L 16	San Miguel	-120.4124510	34.1210120	-120.3648270	34.0876610	5.79
CI_Mar22_L 17	San Miguel	-120.3674640	34.0872130	-120.4140950	34.1201030	5.78
CI_Mar22_L 18	San Miguel	-120.3939450	34.1318300	-120.4584150	34.0857670	8.08
CI_Mar22_L 19	San Miguel	-120.4537030	34.0930260	-120.4157470	34.0663070	4.64
CI_Mar22_L 20	San Miguel	-120.4114910	34.0672530	-120.4499840	34.0947590	4.78
CI_Mar22_L 21	San Miguel	-120.4380780	34.1023910	-120.3950760	34.0724100	5.25
CI_Mar22_L 22	San Miguel	-120.3841880	34.0786280	-120.4145350	34.1002620	3.78
CI_Mar22_L 23	San Miguel	-120.3828120	34.1207760	-120.4001060	34.1086410	2.15
CI_Mar22_L 24	San Miguel	-120.3928140	34.1057500	-120.3764970	34.1173140	2.03
CI_Mar22_L 25	San Miguel	-120.3734370	34.1042930	-120.3827470	34.0973230	1.18
CI_Mar22_L 26	San Miguel	-120.4024500	34.0826860	-120.4182940	34.0719200	1.92



Northern San Miguel Island study area transects shown in green, collected 8 March 2022.

Survey Area: ANA

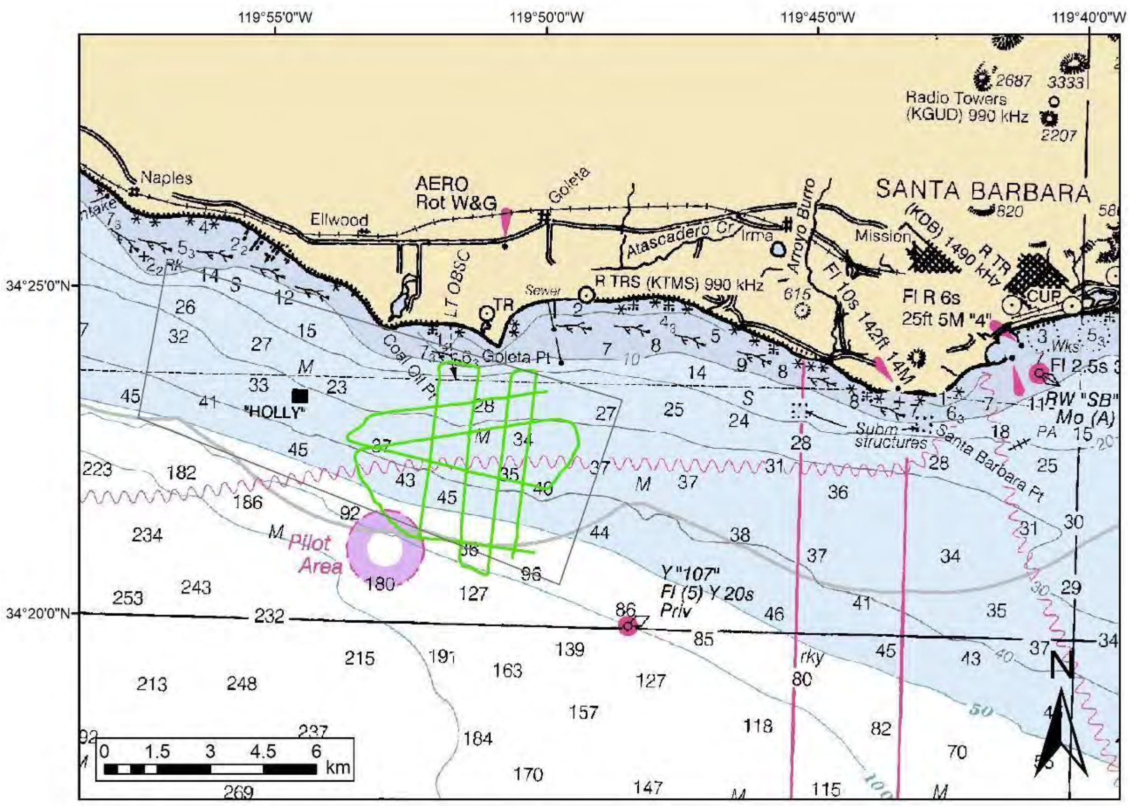
Line	Area	Start		End		Length (km)
CI_Mar22_ L27	Anacapa Is.	-119.4073400	34.0589033	-119.4157267	34.0167833	4.75
CI_Mar22_ L28	Anacapa Is.	-119.4008633	34.0165417	-119.3934650	34.0611083	5.00
CI_Mar22_ L29	Anacapa Is.	-119.3810500	34.0489600	-119.4224267	34.0513933	3.85
CI_Mar22_ L30	Anacapa Is.	-119.4223250	34.0443883	-119.3813200	34.0408883	3.81
CI_Mar22_ L31	Anacapa Is.	-119.3820067	34.0334733	-119.4243550	34.0384900	3.97
CI_Mar22_ L32	Anacapa Is.	-119.4246383	34.0312617	-119.3834400	34.0263400	3.85
CI_Mar22_ L33	Anacapa Is.	-119.3843783	34.0203383	-119.4265550	34.0247250	3.93



Northern Anacapa Island study area transects shown in green, collected 9 March 2022.

Survey Area: COP

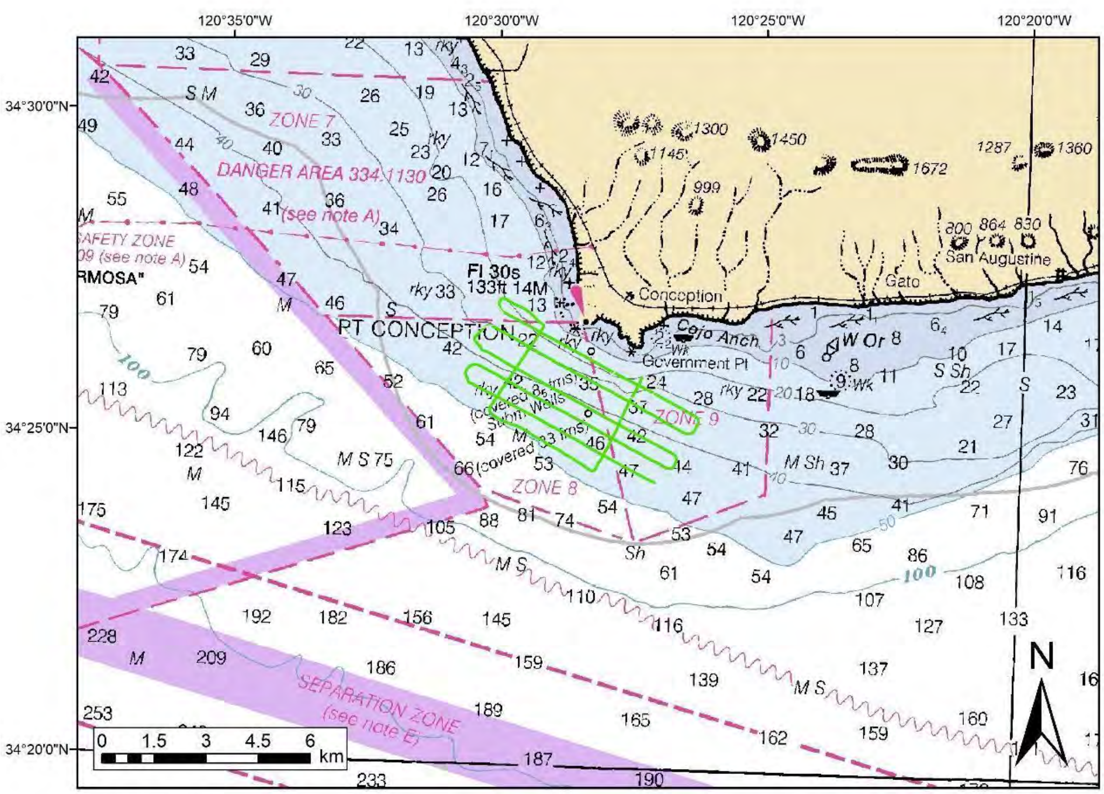
Line	Area	Start		End		Length (km)
CI_Mar22_L 34	La Goleta	-119.8301817	34.3931633	-119.8830817	34.3858983	4.95
CI_Mar22_L 35	La Goleta	-119.8893383	34.3788700	-119.8301650	34.3683800	5.58
CI_Mar22_L 36	La Goleta	-119.8272683	34.3861267	-119.8858683	34.3772083	5.49
CI_Mar22_L 37	La Goleta	-119.8688200	34.3551050	-119.8327000	34.3520000	3.35
CI_Mar22_L 38	La Goleta	-119.8392050	34.3505283	-119.8335283	34.3970817	5.21
CI_Mar22_L 39	La Goleta	-119.8411917	34.3963300	-119.8465633	34.3474683	5.45
CI_Mar22_L 40	La Goleta	-119.8555300	34.3501617	-119.8512583	34.3970467	5.24
CI_Mar22_L 41	La Goleta	-119.8635383	34.3983433	-119.8678383	34.3544250	4.92



La Goleta study area transects shown in green, collected 10 March 2022.

Survey Area: PtC

Line	Area	Start		End		Length (km)
CI_Mar22_L 42	Pt. Con	-120.4522350	34.4346600	-120.4657317	34.4109717	2.92
CI_Mar22_L 43	Pt. Con	-120.4994983	34.4255017	-120.4838233	34.4465950	2.76
CI_Mar22_L 44	Pt. Con	-120.4977133	34.4529883	-120.4352900	34.4250583	6.62
CI_Mar22_L 45	Pt. Con	-120.4385450	34.4205733	-120.5003750	34.4468683	6.40
CI_Mar22_L 46	Pt. Con	-120.5027217	34.4405300	-120.4422783	34.4153333	6.23
CI_Mar22_L 47	Pt. Con	-120.4449800	34.4119750	-120.5063400	34.4318533	6.84
CI_Mar22_L 48	Pt. Con	-120.5062117	34.4318033	-120.4473817	34.4075183	6.05



Point

Conception study area transects shown in green, collected 11 March 2022.

ROV DIVE LOGS

ROV Dives	General Location	Local				Sample	Sample Location		Notes
		Date Start	Time Start	Date End	Time End		Latitude	Longitude	
1	North of Anacapa	1/6/2023	18:56						
		1/6/2023	21:08			SR2301_Anacapa_Rk1	-119.4143382	34.02334504	Sample may be slate
2	North of Anacapa	1/6/2023	22:35	1/7/2023	4:00				Deployed 250 meters west of 119 25.030, 34 2.262. Surveyed until 0400 01/07/23 with no signs of seepage, bubbles, or outcrops.
3	North of Anacapa	1/7/2023	4:33	1/7/2023	6:13				Targeting large pockmarks at 34 2.932, 119 26.007. Beggiatoa mats are abundant (at the 48 minute mark in the video to the 1:39). Mats reencountered in video at 1:26 until end
		1/7/2023	5:39			SR2301_Anacapa_Rk2	-119.4330675	34.04890669	Barnacle
		1/7/2023	5:46			SR2301_Anacapa_Rk3	-119.4329965	34.04893167	Carbonate(?) located amongst beggiatoa mats
4	La Goleta Seep Field	1/7/2023	19:52	1/7/2023	21:02				Survey started 850 meters south of La Goleta Seep field (34 22.077, 199 51.230) and headed north. Software issues occurred on deployment. Software problems are resolved and ROV is on station at 2000. While ROV was lowered

									to station, the water was clear (good visibility) until 40 meters depth and then visibility was significantly reduced. Visibility was so poor that the survey was not deemed useful Recovered ROV at 0100 01/08/23
5	Area between Santa Cruz Island and Santa Rosa Island	1/8/2023	0:54	1/8/2023	3:17				ROV deployed at 33 59.313, 119 58.620 at 0100 01/08/23. Water depth is 40.5 meters. Water visibility is poor. Recovered ROV at 0300 01/08/23 as conditions worsened and operation could become unsafe.
6	North of San Miguel	1/8/2023	19:49	1/9/2023	2:45				ROV deployed to search for lost chirp in Sept of 2021. Sonar was used to search the area as there was very low visibility. Ended survey at 0245 01/09/23
7	North of Anacapa	1/9/2023	19:35	1/9/2023	22:33				Sea conditions made deployment over pockmarks and mats identified in Dive 3 unsafe. Moved ship closer to Anacapa Island and targeted a 'haystack' feature identified in the chirp data. Once deployed, ROV is at bottom at 1938. Visibility at depth is good. Rocky outcrops encountered at bottom with abundant red corals at 1944. Attempted a sample near this outcrop at 1945 until 2005. Moved toward 34 1.344, 119 23.996 in 50 meter increments. Rocky outcrops abundant. Another sample attempted from 2138 until 21:42. ROV recovered at 22:33.

		1/9/2023	20:05			SR2301_ Anacapa Rk 4	-119.4007 346	34.01941 413	Possibly coral - returned to sea
		1/9/2023	21:42			SR2301_ Anacapa _Rk 5	-119.4004 607	34.022115 64	
8	North of Anacapa	1/9/2023	23:35	1/10/2023	2:03				ROV at depth and on station at 23:45 above pockmarked bottom identified on Dive 3. Outcrop encountered at 23:56 and a sample was attempted. Beggiatoa mats begin (sparse) at 0001 amongst abundant rock outcrops. White coating (mats?) on ~20 cm rock outcrop at 0049. Large sample of outcrop recovered at 00:54. Sparse white mats encountered at 0112 (near 34 02.937, 119 25.808). Bubbles released from rock when disturbed at 01:16.. Sample collected at 01:17. Manipulator arm breaks during sampling. ROV recovered at 0203.
		1/9/2023	23:57			SR2301_ Anacapa Rk6	-119.4329 541	34.04894 811	Carbonate(?)
		1/10/2023	0:54			SR2301_ Anacapa Rk7	-119.4321 388	34.04912 087	Large rock sample (carbonate?)
		1/10/2023	1:15			SR2301_ Anacapa _Rk8	-119.4301 845	34.048911 97	Carbonate (?)

9	North of Anacapa	1/10/2023	4:14	1/10/2023	6:00				ROV repaired and redeployed. ROV at seafloor at 0421. Mats encountered on seafloor (sparse and splotchy) from 0421 until 0434. NOTE: Video feed malfunctioned at the beginning of the survey (didn't start until 05:14)
10	North of Anacapa	1/10/2023	18:42	1/10/2023	20:38				ROV on bottom at 18:50 targeting possible rock outcrops near Anacapa Island. Abundant rock outcrops with corals encountered throughout dive. Rock sampled at 1919. Rock outcrops, possibly shale or slate, observed at 1938. Skid on ROV stopped functioning at 20:38; ended survey and recovered ROV.
		1/10/2023	19:19			SR2301_Anacapa_Rk9	-119.4144738	34.02256968	
		1/10/2023	20:16			SR2301_Anacapa_Rk10	-119.4133448	34.02248595	
11	North of Anacapa	1/10/2023	21:20	1/10/2023	23:54				ROV deployed 21:20. ROV at bottom at 21:27. ROV starts transiting toward 34 1.408, 119 24.757. Rock outcrops with clear bedding observed at 21:37 and periodically encountered during dive. Many of the outcrops are followed by overhangs and large drops. Corals observed at each outcrop.

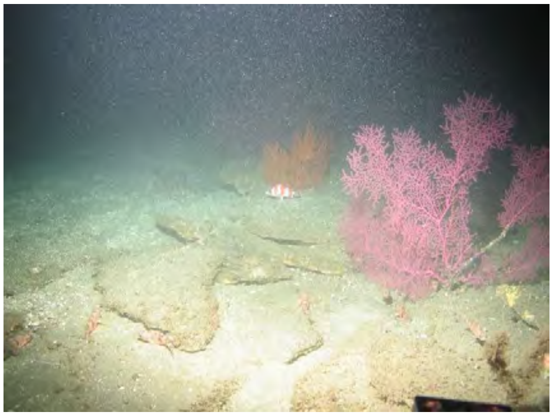
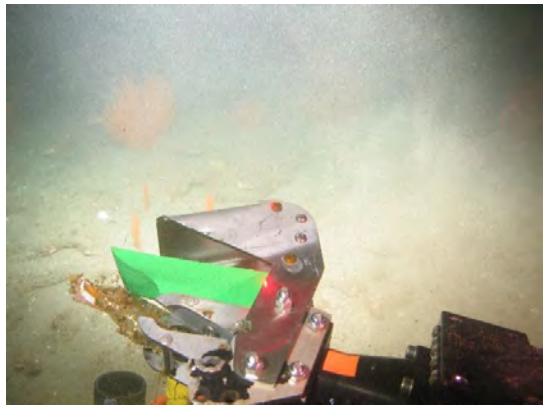
		1/10/2023	21:50			SR2301_Anacapa_Rk11	-119.4123897	34.02343211	
		1/10/2023	22:07			SR2301_Anacapa_Rk12	-119.4102976	34.02359386	
		1/10/2023	23:31			SR2301_Anacapa_Rk13	-119.3992758	34.02238109	
12	North of Anacapa	1/11/2023	0:55	1/11/2023	2:15				ROV in water at 00:55 at 34 2.78, 119 25.538. ROV at bottom at 01:02. Transiting toward 34 2.689, 119 25. 345 (where pockmarks are observed in the bathymetry). Sandy seafloor with abundant sea urchins. At 01:37, bacterial mats observed (fairly strong) at ~34 2.687, 119 25.348. Dark grey to black splotches (stained sediment?) on seafloor both below sea urchins and surrounding bacterial mats (approx. location 34 2.682, 119 25.345). Dark seafloor sediment sampled - SR2301_anacapa_Sd1. Organic debris (sticks, shells, possible bone, dead corals, etc.) observed in large quantities at 01:54 (approx. location: 34 02.684, 119 25.338). Large (2 to 3 meters across) white mat with dark staining underneath observed at 02:00 (approx. location: 34 2.687,

									119 25.345). ROV recovered at 0215.
		1/11/2023	1:50			SR2301_Anacapa_Sd1	-119.4224074	34.04469924	Dark/stained seafloor sediment
13	North of Anacapa	1/11/2023	2:54	1/11/2023	5:22				ROV at bottom at 0254. Bacterial mats observed and sampled at 0300, 0302, and at 0335. End of survey at 05:22
		1/11/2023	3:00			SR2301_Anacapa_Sd2	-119.4224408	34.04476961	Large bacterial mat
		1/11/2023	3:02			SR2301_Anacapa_Sd3	-119.4223311	34.04471477	Large bacterial mat
		1/11/2023	3:12			SR2301_Anacapa_Rk14	-119.422481	34.04478247	Carbonate?
		1/11/2023	3:22			SR2301_Anacapa_Sd4	-119.422319	34.0447629	Sediment under shell hash

Dive 1 & 2

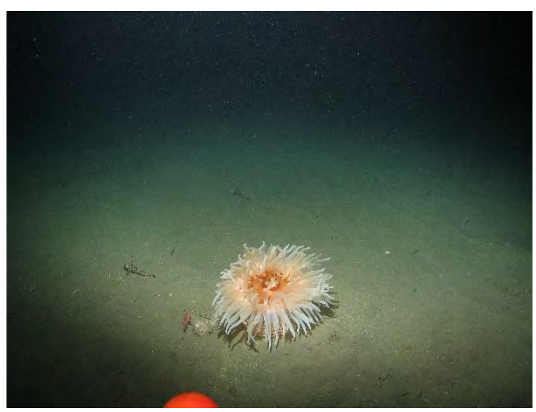
Deployed: 01/06, 18:56; Retrieved 01/07, 04:00 (9 hr 4 min)

Dive 1 had two areas for survey focus. The first was nearest the island and the target was a CSEM resistor coupled with a stringy signal on the subbottom data and rocky dipping bed bathymetry evident. The second was to the north and the target was a CSEM resistor coupled with a discrete subbottom signal and possible seafloor pockmarks evident on the bathymetry. One sample was collected: SR2301_Anacapa_Rk1. There was no obvious feature creating the coupled CSEM/subbottom signals.

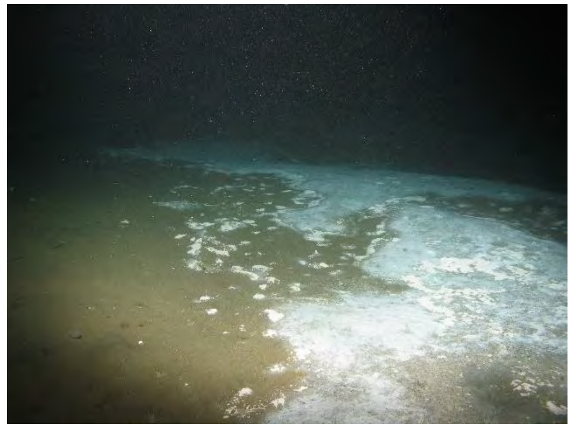
Left: Example of seafloor during Dive 1. Right: Manipulator arm grabber with rock sample, SR2301_Anacapa_Rk1.

Dive 2 was designed to follow the transects of the CSEM and subbottom to identify areas of coupled signals along a path, as a distinct CSEM resistor coupled with a discrete and blotchy subbottom signal along an apparent smooth seafloor in large bedform area. Start at 250 meters west of 119 25.030, 34 2.262. There was no obvious feature creating the coupled CSEM/subbottom signals.

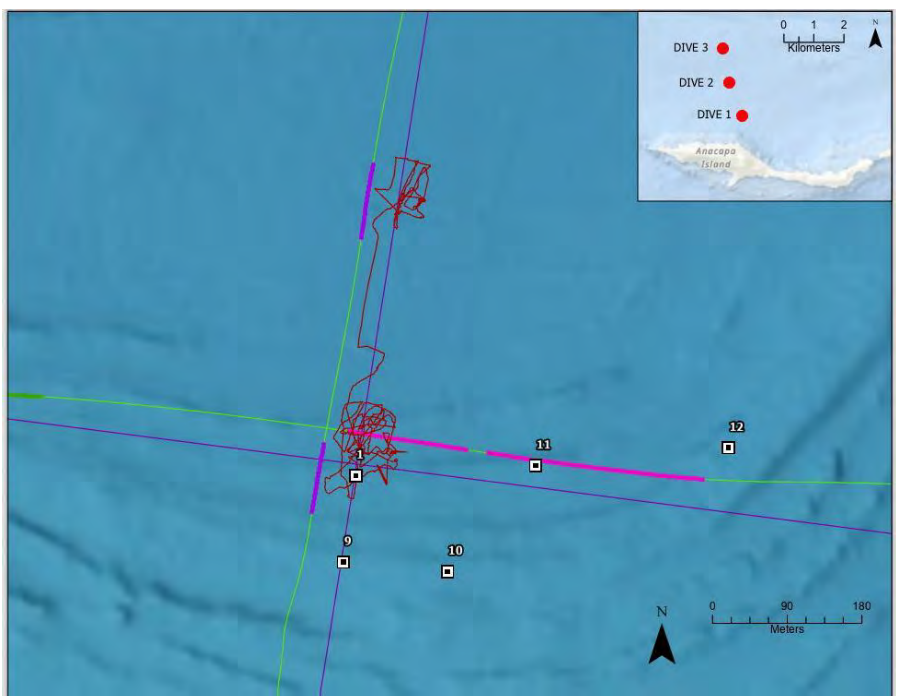



Examples of seafloor during Dive 2.

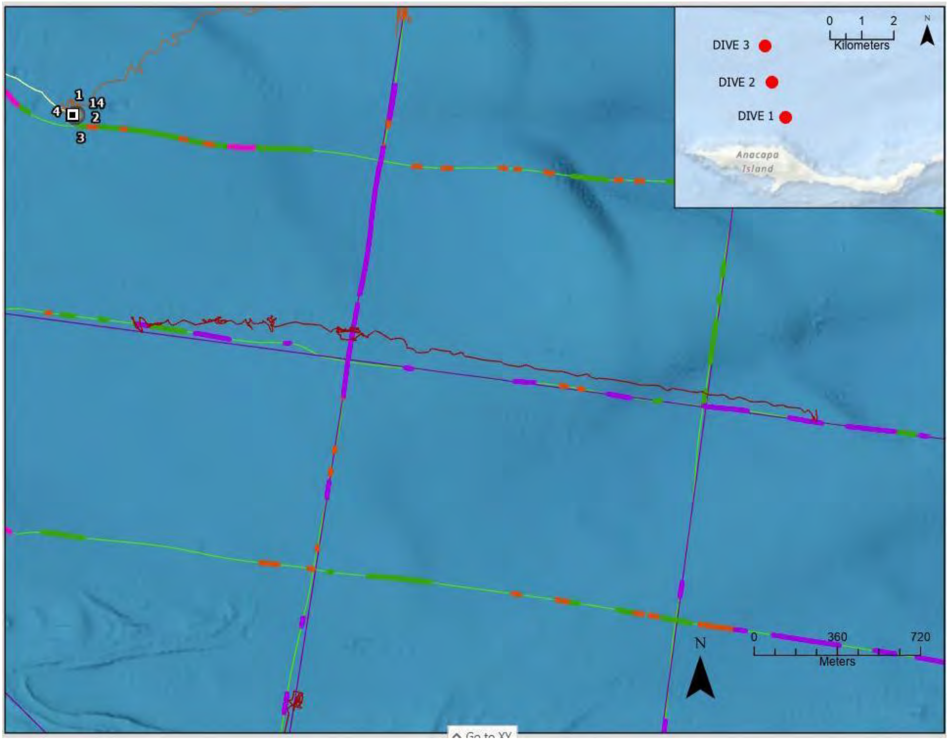
Dive 3
Deployed: 01/07, 04:33; Retrieved 06:13 (1 hr 40 min)
Dive was off the CSEM and subbottom transects and targeted large pockmarks at 34 2.932, 119 26.007. Pocks marks are at times indicative of hydrocarbon and during this dive we identified abundant Beggiatoa mats that are indicative of hydrocarbon seeps. Two samples were collected, SR2301_Anacapa_Rk2 & SR2301_Anacapa_Rk3, that targeted the carbonate created by the bacteria that feeds on the hydrocarbon.



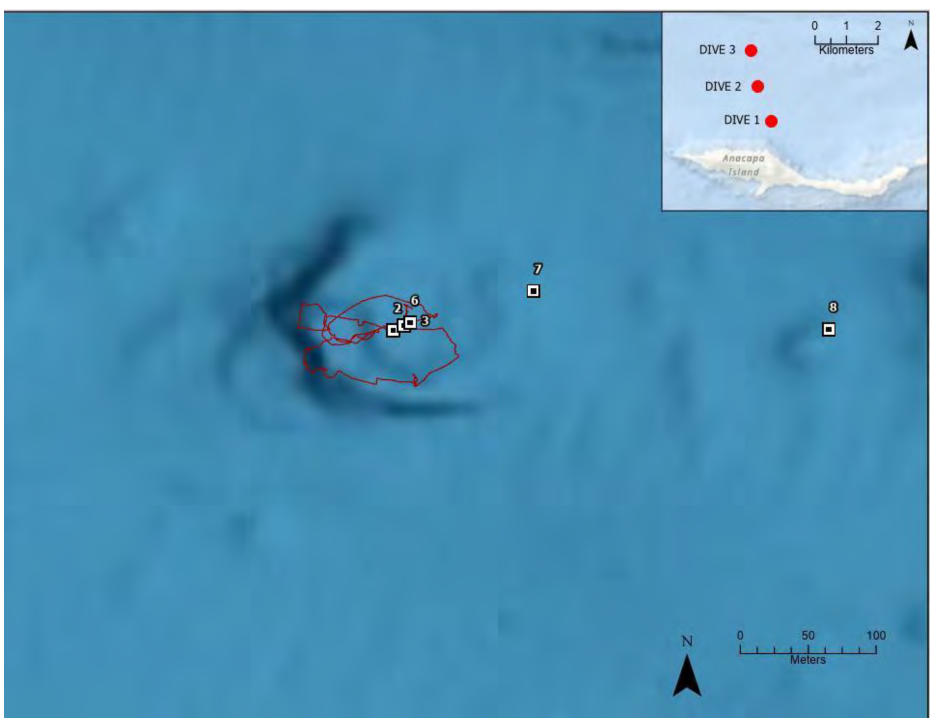
Left: Possible carbonate created by bacteria. Right: Beggiatoa mats that are indicative of hydrocarbon seeps



ROV path from Dive 1 shown in red. Green and blue lines are CSEM and subbottom transects and purple and pink sections are subbottom signals. Location of sample SR2301_Anacapa_Rk1 is shown as 1.



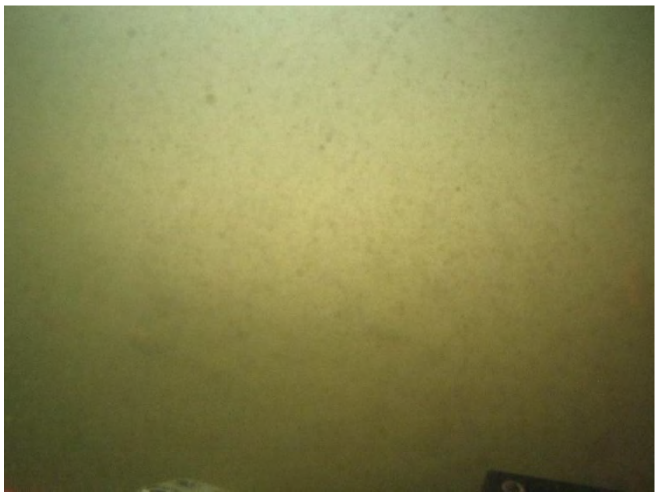
ROV path from Dive 2 shown in red. Green and blue lines are CSEM and subbottom transects and purple, and orange sections subbottom signals.



ROV path from Dive 3 shown in red. Location of sample SR2301_Anacapa_Rk2 and SR2301_Anacapa_Rk2 are shown as 2 & 3.

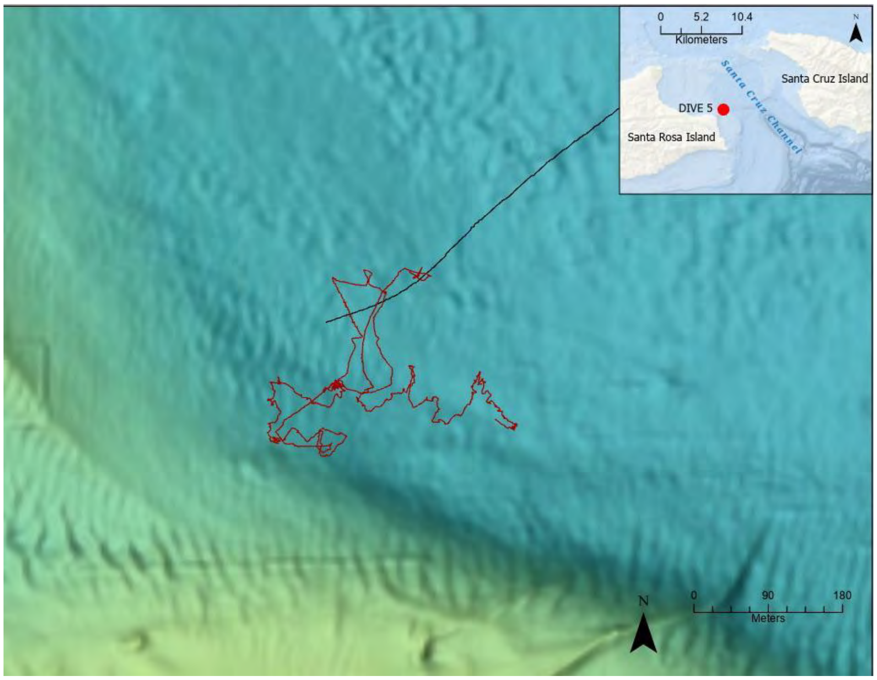
01/07-01/08: Survey Area – La Goleta Seep Field & East of Santa Rosa Island
Start time: 01/06, 18:56 / End time: 01/07, 06:13

Dive 4
Deployed: 01/07, 19:52; Retrieved 21:02 (1 hr 10 min)
This dive targeted the La Goleta seep fields, where there are numerous known tar seeps of varying types. The survey started 850 meters south of La Goleta Seep field (34 22.077, 199 51.230) and headed north. Software issues occurred on deployment. Software problems are resolved and ROV is on station at 2000. While ROV was lowered to station, the water was clear (good visibility) until 40 meters depth and then visibility was significantly reduced. Visibility was so poor that the survey was not deemed useful and the ROV was Recovered ROV at 21:02


Poor visibility at depth at La Goleta Seep Field.

Dive 5
Deployed: 01/08, 00:54; Retrieved 03:17 (2 hrs 23 min)
Dive targeted an area just east of Santa Rosa Island. Previous CSEM and subbottom identified a fault at this location with a possible tar seep. The ROV was deployed at 33 59.313, 119 58.620. Water visibility was relatively poor and sea state began to worsen quickly. Shortly after the ROV reached depth, the captain asked that the instrumentation be retrieved due to sea conditions.

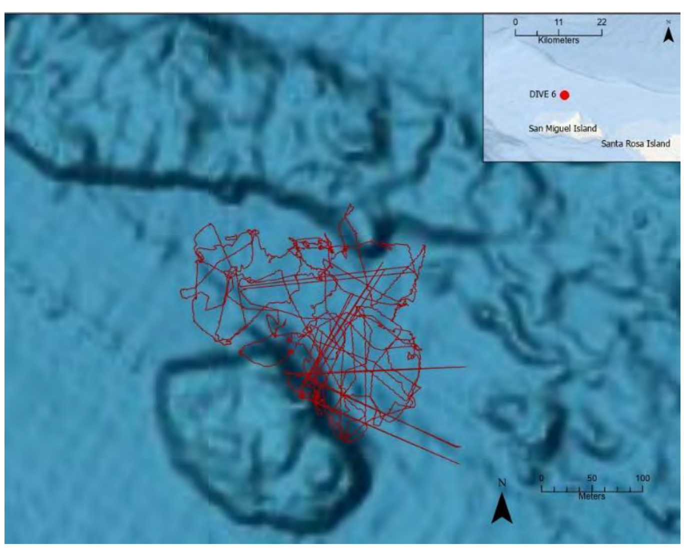

Poor visibility at depth at east of Santa Rosa Island.



ROV path from Dive 5 shown in red.

01/08-01/09: Survey Area - North of San Miguel
Start time: 01/08, 19:49 / End time: 01/09, 02:45

Dive 6
Deployed: 01/08, 19:49; Retrieved 01/09, 02:45 (6 hr 56 min)
ROV deployed to search for Chirp lost in Sept of 2021 just north of San Miguel Island. This area also had a couple targets to search for hydrocarbon. Visibility was low and a sonar that was atop the ROV was used to search the area. The Chirp was not identified and the visibility was too poor to search for hydrocarbon.

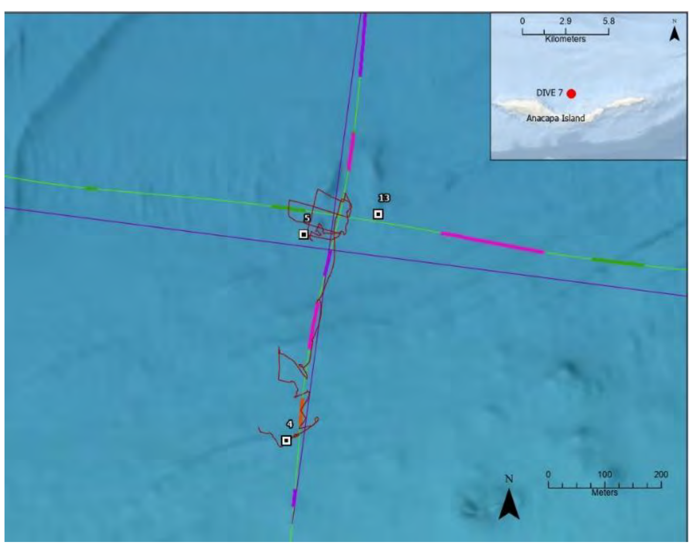


ROV path from Dive 6 shown in red.

01/09-1/10: Survey Area - North of Anacapa
Start time: 01/09, 19:35 / End time: 01/09, 04:14

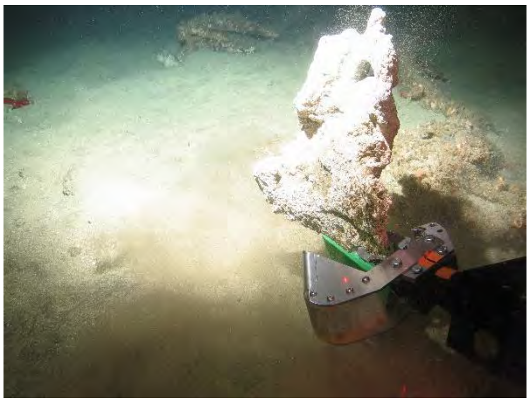
Dive 7
Deployed: 01/09, 19:35; Retrieved 01/09, 22:33 (3 hrs 8 min)
At this point in the project, all areas for survey were either unsafe due to the storm or the visibility was too poor to conduct an ROV dive. The area north of Anacapa was generally protected from the storm, but even this area was impacted this evening. We planned to dive on the pockmarks and mats identified in Dive 3, but needed to move closer to the island to shelter from the storm. We targeted a 'haystack' feature identified in the chirp data, which was located closer to the north shore of Anacapa Island. Rocky outcrops were abundant in this region, some with red coral. We collected two samples: SR2301_Anacapa_Rk 4 & SR2301_Anacapa_Rk 5.

Outcrop with red coral.

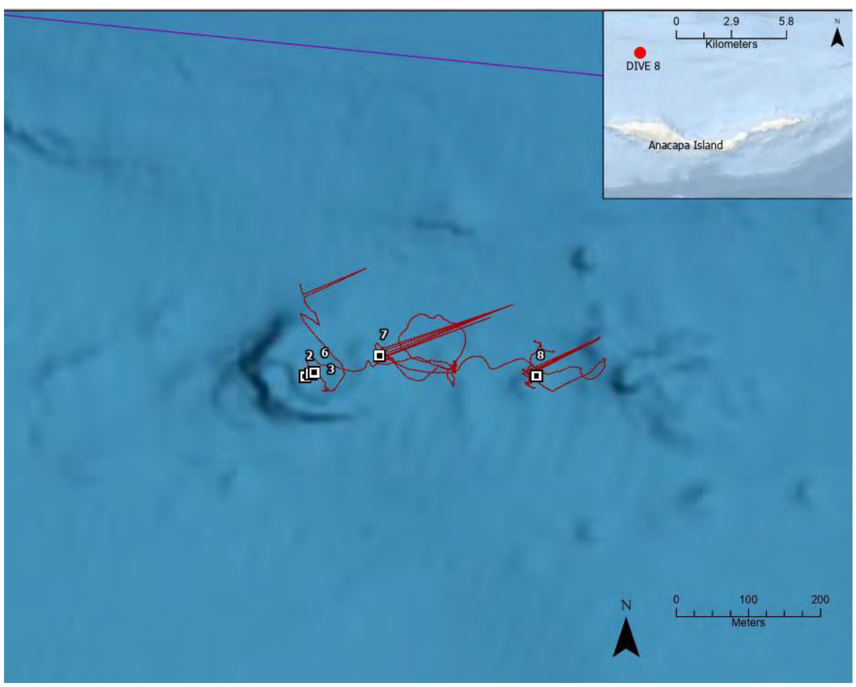


ROV path from Dive 7 shown in red. Green and blue lines are CSEM and subbottom transects and purple, and orange (haystack) sections subbottom signals. Location of sample SR2301_Anacapa_Rk4 and SR2301_Anacapa_Rk5 are shown as 4 & 5.

Dive 8
Deployed: 01/09, 23:35; Retrieved 01/10, 02:03 (2 hrs 38 min)
The sea state improved and we were able to survey the pockmarked bottom identified on Dive 3. Numerous outcrops were identified and Beggiatoa mats are intermixed. We collected three samples from near the outcrops: SR2301_Anacapa_Rk 6, SR2301_Anacapa_Rk 7, SR2301_Anacapa_Rk 8. We assume they samples are carbonate created by the bacteria. During sampling, bubbles were released from rock when disturbed by the manipulator arm indicating hydrocarbon seeps. Manipulator arm breaks during sampling and is recovered for repair.



Left: Rock sample covered in Beggiatoa. Right. Example of outcrops in area.

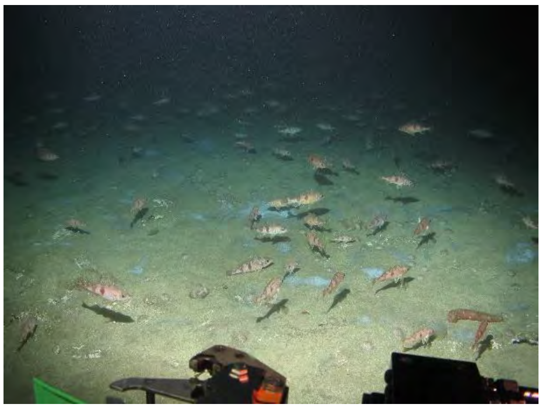


ROV path from Dive 8 shown in red. Samples SR2301_Anacapa_Rk 6, SR2301_Anacapa_Rk 7, SR2301_Anacapa_Rk 8 shown as 6, 7, & 8.

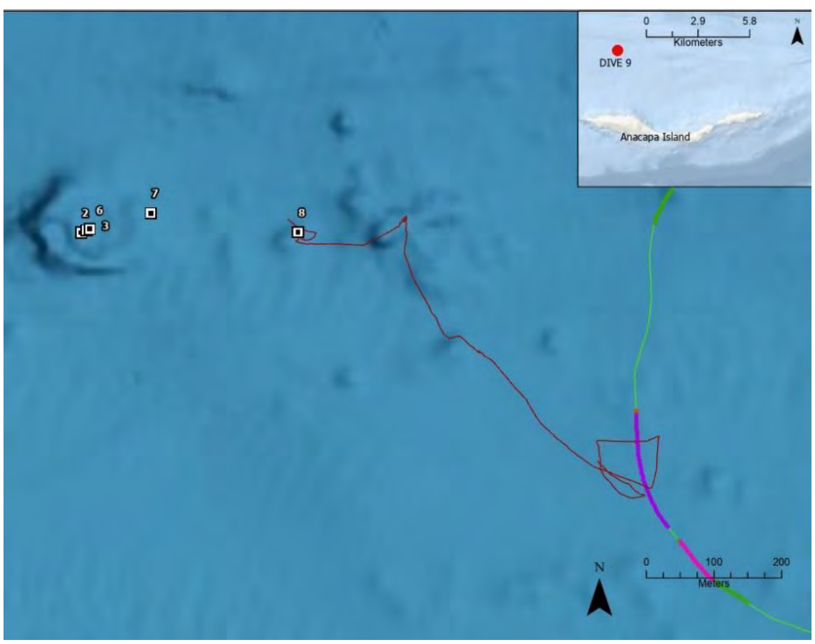
<u>Dive 9</u>

Deployed: 01/10, 04:14; Retrieved 01/10, 06:00 (1 hr 46 min)

The ROV manipulator arm was repaired and we redeployed the instrument at the last sample location. We continued to see the Beggiatoa mats which became more sparse and patchy as we drove east. We surveyed southeast to continue along the pockmarked bottom and headed to a section along our subbottom that had various types of subbottom signals. There was no obvious landform for the signals. NOTE: Video feed malfunctioned at the beginning of the survey and it did not start recording until 05:14.



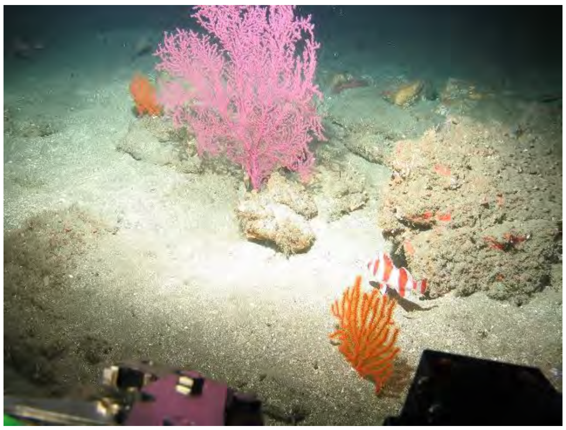

Sparse and patchy Beggiatoa mats.



ROV path from Dive 9 shown in red. Green and blue lines are CSEM and subbottom transects and purple, pink, and orange sections are subbottom signals.

01/10 – 01/11: Survey Area - North of Anacapa
Start time: 01/10, 18:42 / End time: 01/11, 05:22

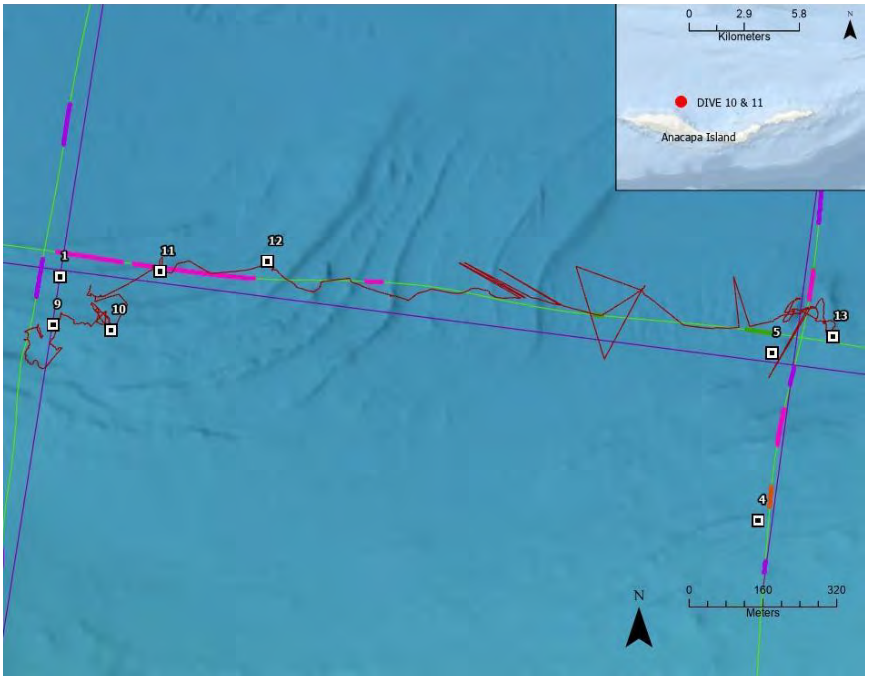
<u>Dive 10</u>
Deployed: 01/10, 18:42; Retrieved 01/10, 20:38 (1 hr 56 min)
We returned to the area surveyed during Dive 1 due to the abundant outcrops identified there. Abundant rock outcrops with corals encountered throughout dive. We collected two samples: SR2301_Anacapa_Rk 9 & SR2301_Anacapa_Rk 10. Skid on ROV stopped functioning at 20:38; ended survey and recovered ROV.




Left: Rock outcrops with coral. Right: Sample collected during dive.

<u>Dive 11</u>
Deployed: 01/10, 21:20; Retrieved 01/10, 23:54 (2 hrs 14 min)
ROV deployed at retrieval location from Dive 10. This dive traced rock outcrops shown along bathymetry and subbottom data. Rock outcrops with clear bedding were observed at periodically during dive. Many of the outcrops were followed by overhangs and large drops. Corals observed at each outcrop. Three samples were collected: SR2301_Anacapa_Rk 11, SR2301_Anacapa_Rk 12, SR2301_Anacapa_Rk 13.


Examples of outcrops with coral identified during dive.

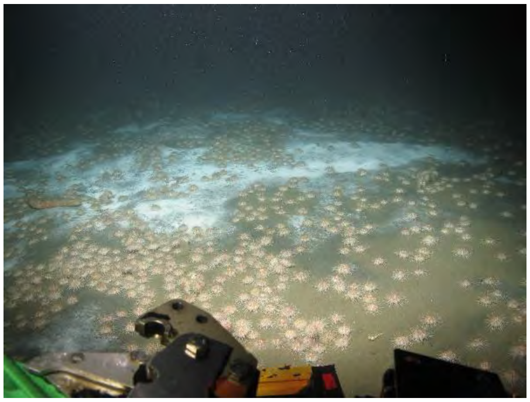


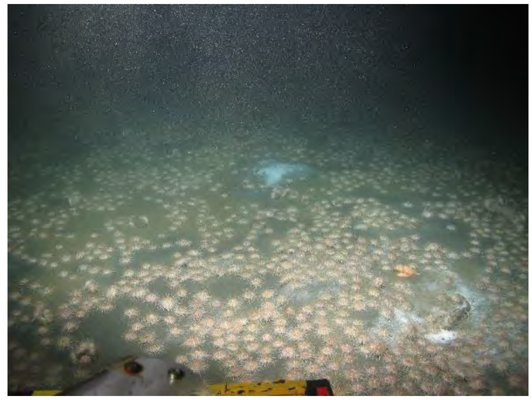
ROV path from Dives 10 and 11 shown in red. Samples SR2301_Anacapa_Rk 11, SR2301_Anacapa_Rk 12, SR2301_Anacapa_Rk 13 are shown as 11, 12, & 13.

Dive 12
Deployed: 01/11, 00:55; Retrieved 01/11, 02:15 (1 hr 20 min)

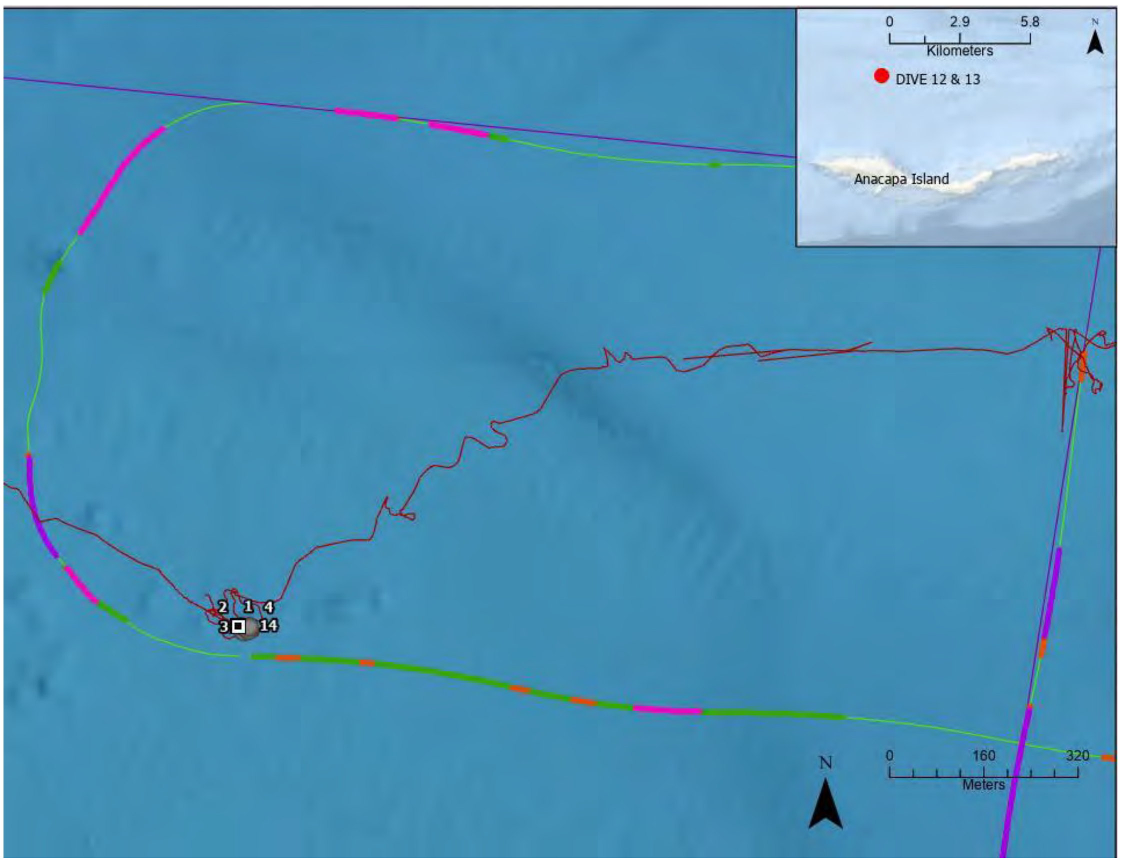
Dive 13
Deployed: 01/1, 02:54; Retrieved 01/11, 05:22 (2 hrs 28 min)

Dives 12 and 13 are the last two dives and are targeting the pockmarked bottom and focusing on gathering samples of the Beggiatoa mats. These were split into two dives as we retrieved the ROV part way through to retrieve samples and re-deploy. There was sandy seafloor with abundant sea urchins in the west section of the dive area. Bacterial mats along with dark grey to black splotches on seafloor were observed. These areas also had abundant sea urchins. Dark seafloor sediment was sampled - SR2301_anacapa_Sd1. Organic debris (sticks, shells, possible bone, dead corals, etc.) was observed in large quantities in a discreet location that we assumed to be an eddy. Large (2 to 3 meters across) white mat with dark staining underneath observed 34 2.687, 119 25.345. We sampled the bacterial mats- SR2301_Anacapa_Sd2, SR2301_Anacapa_Sd3, SR2301_Anacapa_Sd4 and collected one more rock sample, SR2301_Anacapa_Rk 14. We then retrieved the ROV for the end of the survey and project at 05:22. This was a hard stop in order to transit back to MARFAC and arrive by our scheduled time.





Examples of dark staining of sea floor with bacteria mats and sea urchin.



ROV path from Dives 12 & 13 shown in red. Rock sample SR2301_Anacapa_Rk 14 shown as 14. Sediment samples SR2301_Anacapa_Sd1, SR2301_Anacapa_Sd2, SR2301_Anacapa_Sd3, and SR2301_Anacapa_Sd4 shown as 1, 2, 3, & 4.

APPENDIX E

Definitions

Definitions

1. Paleochannels: Remnants of a river or stream that flowed in the past, but now has a channel that is infilled with sediment and is no longer part of an active fluvial system. Paleochannels can be on the drowned remnants of once subaerial landscapes.

2. Paleoestuaries: Remnants of a once active estuary that has been submerged by sea level rise and infilled with sediment.

3. Offshore tar seeps: Locations on the sea floor where asphalt escapes through the earth's surface. Tar seeps are known as locales that can trap various organisms resulting in a record of local plants and animals.